Assessment of most promising measures

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Task 3

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Preface

The results presented in this report are based on desk and modelling studies.
The report benefited from discussions with many colleagues.
A draft version was commented by Michel Sponar and
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Summary

The background of this assessment report is the EU Thematic Strategy on Air Pollution (TSAP). In the TSAP, the European Commission outlined the strategic approach towards cleaner air in Europe (CEC, 2005). To decrease the emissions of ammonia (NH_3) from agriculture, the following approaches were identified:

1) The National Emission Ceiling Directive (NEC) (2000/1258/EC) will be reviewed in 2007 and emission reduction targets will be fixed that are needed to meet the environmental and health objectives of the Thematic Strategy on Air Pollution. In the framework of the revision of the emission ceilings under the NEC, integration of new objectives for eutrophication, acidification and for particulate matter are required.
2) A possible extension of the Integrated Prevention and Pollution Control Directive (IPPC) to include installations for intensive cattle rearing and a possible revision of the current thresholds for installations for the intensive rearing of pigs and poultry. The review of the IPPC is done parallel to the TSAP.
3) In the context of the Rural Development Regulation for the period 2007-2013, the Commission encourages Member States to make full use of the measures related to farm modernisation, meeting standards and agro-environment to tackle NH_3 emissions from agricultural sources.

During the preparation of the TSAP, the desired integrated approach was only partly taken into account, because no tools were available to assess for example the effect of measures taken to decrease NH_3 emission on nitrate losses to the aquatic environment. Also, no assessments were available about the impact of measures taken in the framework of the Nitrates Directive to decrease nitrate emissions to water, on NH_3, nitrous oxide (N_2O) and methane (CH_4) emissions. Further, the impact of the reform of the Common Agricultural Policy (CAP) on N use in agriculture and N emissions from agriculture were not addressed in the preparation of the TSAP. Hence, further studies were needed to be able to implement the integrated approach set out by the TSAP.

Within the Service Contract No 070501/2005/422822/MAR/C1- "Integrated measures in agriculture to reduce ammonia emissions", Task 3 deals with 'promising measures' to decreasing N losses from EU agriculture. The aim of Task 3 has been defined as *(i) to identify a list of most promising (package of) measures to decrease the emissions of ammonia, nitrous oxide and methane to the atmosphere and nitrate to groundwater and surface waters, (ii) to select three (packages of) most promising measures after a dialogue with the Commission, and (iii) to make an in-depth assessment of the cost and impact of these (packages of) most promising measures".* In order to be considered as promising, the (package of) measure should correspond to the following criteria:

(i) Co-beneficial effects for water, air, climate change and soil protection;
(ii) Feasible notably from an administrative and enforceability point of view;
(iii) Potentially acceptable by the farmers notably for what concerns costs and additional efforts at farm level;
(iv) Compatibility with the need for improved animal welfare'.

This report deals with the identification and selection of 'most promising measures', provides justification for the approach and assumptions in the model assessments, and presents the results of the assessments. The most promising measures assessed are:

(i) improving N use efficiency in animal production and lowering the N excretion of livestock through improved animal feeding (low-protein animal feeding)
(ii) improving N use efficiency in crop production and lowering N input in agriculture through balanced N fertilization; and
(iii) combination of most promising measure (ii) plus enforced implementation of technical measures to decrease NH_3 emissions.
The assessments have been carried out using the integrated assessment tools MITERRA-EUROPE and CAPRI. Both models allow the assessment of the effects of various measures on the emissions of N to the atmosphere, groundwater and surface waters. In addition, CAPRI is an economic optimization tool which allows making economic assessments of the promising measures.

The results indicate that the implementation of low-protein animal feeding has multiple beneficial environmental effects. The assessments by MITERRA-EUROPE indicates that a decrease of 10% in the protein content of the animal feed on all farms will lower the NH_3 emissions by about 5% and the N leaching and emissions of N_2O by about 3% relative to the ND full 2020 reference scenario. This indicates that low-protein animal feeding has synergistic effects. Decreasing the protein content of the animal feed by 20% would further decrease the NH_3 emissions by 10% and the N leaching and emissions of N_2O by 6% relative to the ND full 2020 reference scenario. Hence, the effects of the decreases in protein content are suggested to be linear.

Balanced N fertilization also has multiple beneficial environmental effects. Full implementation of balanced fertilization according MITERRA-EUROPE in this study (removing ‘over-fertilization’) was equivalent to decreasing the N input via N fertilizer by on average 11% and that via animal manure by up to 13%, relative to the ND full 2020 reference scenario. Balanced fertilization (Balfert 2020) decreases the NH_3 emissions by 6%, N leaching by 14% and the emissions of N_2O by 6% relative to the ND full 2020 reference scenario. However, balanced fertilization as applied in this study is not without cost for the farmer. It may increase the risk of a decrease in crop yield. Furthermore, areas with high livestock density may be forced to lower the N content of the animal manure through low-protein animal feeding or may have to treat the manure, to be able to implement balanced fertilization and to utilize the nutrients in the animal manure efficiently. The balanced N fertilization measure has considerable perspectives for decreasing the N loading of the environment, but when applied too strict it can have considerable agronomic and economic effects. Further sensitivity analyses are needed.

Combined implementation of an optimal set of NH_3 emission abatement measures (RAINS optimized 2020) and balanced fertilization (‘Optimal Combination 2020’) has also ‘far-reaching’ effects. According MITERRA-EUROPE simulations, it decreases the NH_3 emission by another 20% relative to the ND full 2020 reference scenario to a level of ~ 2380 kton NH_3 from agriculture in EU-27. This level is below the target levels (~ 2450 kton for EU-25 and ~2650 kton for EU-27; Aman et al., 2006b) needed to achieve the objectives of the Thematic Strategy on Air Pollution in 2020. In addition, the Optimal Combination 2020 scenario decreases mean N leaching by 17% and mean N_2O emissions by 4% relative to the ND full 2020 reference scenario. However, the Optimal Combination 2020 scenario is not without cost for the farmer. The annual cost of the NH_3 emission abatement measures have been estimated at € 1.6

billion for the EU-25, in addition to the cost already associated with current legislation. Further, relatively large amounts of manure N have to be 'neutralized' through a combination of low-protein animal feeding and manure treatment and manure disposal in some regions, at considerable additional costs.

The key results from the CAPRI simulations are summarized in Table A.

Table A. Simulation results of low nitrogen feeding, balanced fertilization and 'optimal combination' measures vs. ND full 2020 in EU2, using CAPRI.

	agric income [m €]	consumer welfare [m €]	total econ welfare [m €]	total NH3 loss [kton]	total CH4 emisions [kton N]	total N2O emisions [kton N]	leaching [kton N]
BALFERT	-2130	116	-2027	-145	2	-50	-416
LNF10 all	-6089	-2910	-10682	-205	70	-36	-127
LNF10 IPPC	-197	-1635	-2041	-36	12	-6	-14
LNF20 all	-732	-23767	-30280	-445	-341	-82	-267
Opt combination	-9603	-3797	-15018	-651	38	-50	-527

	abatement relative to welfare cost estimate			
	NH3 [g / €]	CH4 [g / €]	N2O [g / €]	leaching [g / €]
BALFERT	72	-1	25	205
LNF10 all	19	-7	3	12
LNF10 IPPC	18	-6	3	7
LNF20 all	15	11	3	9
Opt combination	43	-3	3	35

Clearly, balanced fertilization achieves significant improvements on leaching and also ammonia at moderate cost. Low-protein feeding apparently involved greater losses for the economy per saved emissions but it is important if the contribution of balanced fertilization alone is insufficient. It is evident that a great part of the economic loss is born by consumers. Price increases of 10% and more have been projected under the ambitious variant of low protein feeding and the size of these price increases in part of the uncertainties. Among other influences they hinge on the unknown degree of consumer preferences for EU produced meat which determine the amount of pass through of additional cost in the livestock sector. With greater substitutability the economic losses would fall more on agriculture than on consumers. The optimal combination is shown to yield significant contributions at an economic cost between those of the BALFERT and LNF scenarios. The economic costs do not encompass estimates of the additional administrative cost in EU and national administrations and advisory services. On the other hand the term total welfare cost should not be read as implying that the overall economic balance is negative. As no monetary values have been assigned to the abatements achieved, it is possible and even likely that the overall balance would be positive. The economic welfare costs in Table A have been defined in a quite narrow sense and refer only to the conventional welfare components.

The results of the MITERRA-EUROPE and CAPRI simulations agree rather well. Though the activity data are based on similar sources, the modelling concepts are different. CAPRI is an economic optimization model, while MITERRA-EUROPE largely is an empirical factor model. Both models arrive at the conclusion that the identified most promising measures can contribute greatly to the decrease in the emissions of NH_3 and N_2O to the air and the leaching of N to groundwater and surface waters. However, these benefits are not without costs. The differences between the

MITERRA-EUROPE and CAPRI simulations can be seen as a contribution to sensitivity analyses.

The scope for lowering the total N excretion of animals in the EU-27 by 10 to 20% is based on the following combination of measures:

- lowering the protein content of animal feed, with or without additions of specific amino acids and improved phase feeding;
- improvement of the genetic potential of the herds, i.e., increasing the milk yield per cow and the growth rate of pigs, poultry and beef animals; and
- lowering the replacement rate of dairy cattle, increasing the growth rate of young dairy stock and lowering the age of the young stock at first calving.

The suggested decrease of the N excretion by animals by roughly 10-20% in the next 10 to 15 years will be achieved only with proper incentives, including

- training and advising farmers;
- demonstration trials and demonstration farms;
- covenants with animal feed industry and farmers;
- research for improving the requirement of animals for amino acids and the diagnosis of amino acids in diets.

For making more accurate assessments of the prospects for lowering N excretion through further lowering of the protein content in the animal feed, it is recommended that a thorough survey is being made of the animal feeding practices and animal performances in the EU-27.

1. Introduction

Nitrogen (N) is a key input in agriculture. The availability of relatively cheap N fertilizers from the 20th century onwards has contributed greatly to increased food and feed production, though not equally on all continents (Smil, 2000; 2001). This increased food and feed production allowed the human population to double and the number of domestic animals to triple between 1960 and 2000. Forecasts suggest further increases in human population and animal numbers in the range of 30 to 50%, respectively, suggesting the need for increasing amounts of available N (Bruinsma, 2003; Mosier et al., 2004). Current global N fertilizer use is about 80 billion kg (80 Tg), but not more than 50% of this N is utilized by the crop while the remainder is dissipated into the wider environment (Mosier et al., 2004). On average not more than 30% of the amount of N excreted by livestock (globally 100 - 130 Tg per year) is utilized by the crop, while the remainder is dissipated into the wider environment (Smil, 1999; Oenema and Tamminga, 2006).

In response to the environmental side effects of the increasing N losses from agriculture, especially during the period 1960-1990, series of environmental policies and measures has been implemented in the European Union (EU) from the early 1990s onwards (e.g., Romstad et al., 1997; De Clercq et al., 2001). These policies and measures specifically aim at decreasing the emissions of NH_3 to the atmosphere, the leaching of NO_3^- to groundwater and surface waters, and the emissions of greenhouse gases, notably N_2O, CH_4 and CO_2 to the atmosphere.

There is increasing awareness that the large number of policies and measures might not be the most efficient way of decreasing N emissions. Moreover, there is increasing awareness that measures aiming at decreasing the emissions of one N species or one N loss pathway may increase the emission of another N species and/or another N loss pathway, when the policies and measures are not sufficiently integrated. Evidently, there is need for integrated measures that decrease all N losses from agriculture.

Within the Service Contract No 070501/2005/422822/MAR/C1- "Integrated measures in agriculture to reduce ammonia emissions", Task 3 deals with 'promising measures' to decreasing N losses from EU agriculture. The aim of Task 3 has been defined in the call for tender as *(i) to identify a list of most promising (package of) measures to decrease the emissions of ammonia, nitrous oxide and methane to the atmosphere and nitrate to groundwater and surface waters, (ii) to select three (packages of) most promising measures after a dialogue with the Commission, and (iii) to make an in-depth assessment of the cost and impact of these (packages of) most promising measures".*
In addition, the most effective European and/or national instruments should be identified to implement the most promising measures.

In order to be considered as promising, the (package of) measure should correspond to the following criteria:

- (v) Co-beneficial effects for water, air, climate change and soil protection;
- (vi) Feasible notably from an administrative and enforceability point of view;
- (vii) Potentially acceptable by the farmers notably for what concerns costs and additional efforts at farm level;

(viii) Compatibility with the need for improved animal welfare'.

The call for tender mentioned that "the list of most promising measures will include at least adapted feeding strategies aiming at ensuring the same level of production with reduced nitrogen content in the feed and/or an adaptation of the feeding regime to the level of growth of the animals".

This report focuses on the identification and selection of these single promising measures, provides justification for the approach and assumptions in the model calculations, and presents the results of the assessments.

Chapter 2 deals with the identification and selection of three (packages of) 'most promising measures'. The next three chapters (Chapters 3, 4 and 5) deal with the underpinning and justification of the implementation of these three most promising measures in practice. Chapter 6 deals with the translation of the most promising measures in scenarios. The next two chapters provide the assessments of the scenarios, using the modeling tools MITERRA-EUROPE (Chapter 7) and CAPRI (Chapter 8). Chapter 9 is the General Discussion and conclusion chapter.

2. Selection of measures to decrease nitrogen emissions from agriculture

2.1. Overview of possible measures

A large number of technical, structural and management-related measures for mitigating emissions of ammonia, nitrate, phosphorus, nitrous oxide, methane and carbon dioxide from agricultural systems have been suggested in literature (e.g., Romstad et al., 1997; Hatch et al., 2004; Kuczybski et al., 2005; Cuttle et al., 2004; Mosier et al., 2004; Gairns et al., 2006; Weiske et al., 2006; Soliva et al., 2006). Many of these measures have been reviewed and qualitatively assessed in Task 2 Service Contract No 070501/2005/422822/MAR/C1- "Integrated measures in agriculture to reduce ammonia emissions", and have been summarized in Oenema and Velthof (2007).

Measures for mitigating emissions of ammonia, nitrate, phosphorus, nitrous oxide, methane and carbon dioxide from agricultural systems can be categorized in:
(i) management-related measures,
(ii) technical and technological measures, and
(iii) structural measures.

Management-related measures include best management practices, i.e., improving the operational and tactical management of animal feeding, housing, manure, soils and crops. These measures require increased knowledge and experience of farmers and therefore require training, advice and demonstration, and support by management tools. These types of measures do comply with the criteria of most promising measures indicated in the call for tender.

Technical and technological measures often require investments in 'hardware', in machines, animal housing systems, manure storage and manure application techniques, anaerobic digesters and manure treatment, and air scrubbers. These measures are often costly and also require increased knowledge and experience of farmers and therefore also require training, advice and demonstration, and support by management tools. Some of these types of measures may comply with the criteria of most promising measures but quit a few are (too) costly.

Structural measures are least defined. A distinction can be made between large-scale structural changes and changes in the structure of farming systems. Large-scale structural changes include for example (i) changes in number, type, size of agricultural holdings and in the type and total volume of agricultural production, (ii) changes in the relative importance of production factors and resources (land, labor, capital, energy and management); and (iii) changes in the organization and vertical integration of food producing and food processing chains. These large-scale structural changes do not comply with the criteria of most promising measures, and are therefore not considered further. Farm-scale structural measures relate to changing the structure of the farm, for example from mixed to specialized farming systems, or from landless to mixed livestock systems. It may also relate to clustering and combining various crop and animal production systems to integrated novel systems that have low resource utilization and low emissions per unit of product produced. However, such structural measures (changes) require large capital investments (technical and social) and do not comply with the criteria of most promising measures and are therefore also not considered here further.

Summarizing, most promising measures as defined in the Ammonia Service Contract relate to management-related measures, and to some technical and technological measures. Further, most promising measures must focus on input control, to circumvent or minimize the risk on pollution swapping (see Oenema and Velthof, 2007). Hence, N input control and management-related and technical/technological measures form the building blocks of the most promising measures for mitigating emissions of ammonia, nitrate, phosphorus, nitrous oxide, methane and carbon dioxide from agricultural systems.

2.2. Improving nitrogen use efficiency

Major sources of N in agriculture of EU-27 are N fertilizers (about 10 Tg per year), animal manure (produced about 9 Tg per year; applied to agricultural land about 5 Tg per year), biological N_2 fixation (about 1 Tg per year) and atmospheric N deposition (about 2 Tg). The N from animal manure is derived from animal feed and can be considered as recycled N. Part of this recycled N is derived from imported animal feed. Van Egmond et al., (2002) estimated the amount of N in imported animal feed in Europe at about 7 Tg per year. The N from atmospheric N deposition can be considered also as recycled N; about half is derived from NH_3 emitted from agriculture and the other half is largely derived from NO_X derived from combustion sources. Summarizing, the major sources of 'new' N in agriculture of EU-27 are N fertilizers (~ 10 Tg per year) and imported animal feed (~ 7 Tg per year). Hence, N input control as measure for mitigating emissions of ammonia, nitrate, phosphorus, nitrous oxide, methane and carbon dioxide from agricultural systems, should focus on N fertilizer input and N input via animal feed. Lowering N input can only be considered as 'most promising measure' if crop yields and animal performance is not significantly decreased. Hence, lowering N input is only acceptable as most promising measure if the N use efficiency within agriculture is increased proportionally to keep the production level constant. Improving N use efficiency is therefore another building block of the most promising measures for mitigating emissions of ammonia, nitrate, phosphorus, nitrous oxide, methane and carbon dioxide from agricultural systems.

Improving nitrogen (N) use efficiency in agriculture is considered to be the most promising and most integrated measure to decrease N losses from agriculture (Mosier et al., 2004; Hatch et al., 2004; Kuczybski et al., 2005; Cuttle et al., 2004; Gairns et al., 2006; Weiske et al., 2006; Soliva et al., 2006). Improving N use efficiency means that agriculture produce is made with less N (input) and that N losses are decreased. Improving N use efficiency often requires combination of various management and technological measures, including improved soil, crop and animal management, improved genetic potential of crops and animals, and emission abatement measures. Such packages of measures have to be implemented jointly with a decrease in N input and/or an increase in yield and N off take. Such a strategy has the potential of synergistic effects, i.e. decreasing the losses of all N species at acceptable economic costs, with minimal risk of pollution swapping (see Oenema and Velthof, 2007).

2.3. Selection of most promising measures

Balanced N fertilization in crop production and low-protein animal feeding in animal production combined with low-emission storage, handling and application techniques for animal manure can be seen as the main vehicles to improve N use efficiency in EU agriculture. Balanced N fertilization is an accepted measure of the Nitrates Directive, though only implemented in Nitrate Vulnerable Zones (NVZs). It is suggested now to extent this measure to all agricultural land in the EU-27, also because of its synergistic effects through decreasing emissions of ammonia, nitrate and nitrous oxide simultaneously. The Nitrates Directive in combination with the Water Framework Directive and the Groundwater Directive seem the most likely policy instruments to implement balanced fertilization beyond NVZs.

Low-protein animal feeding in animal production is also an accepted measure in a number of Member States but in the EU-27 only implemented on large pig and poultry farms in the EU-27 through the IPPC Directive (so-called IPPC farms). It is also a measure of the Guidelines for ammonia abatement developed by the Working Group on Ammonia Abatement of the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP). Improving the efficiency of N utilisation at the animal level requires both genetic improvement of the herd, a better description of feed, and higher quality feed with a proper balance of amino acids (and hence a low protein content). The first limitation for animal production and an efficient utilization of feed protein is an adequate supply and intake of feed energy and amino acids in proper ratios. Ensuring low-protein animal feeding in animal production in practice may be achieved through the IPPC Directive on IPPC farms but likely also through the Nitrates Directive. This Directive enforces a maximum application of N via animal manure of 170 kg per ha per year, and thereby exerts influence on lowering the N excretion per animal; the lower the N excretion per animal, the more animals can be kept per ha agricultural land. Alternatively, implementation of low-protein animal feeding in practice may be achieved through communicative and persuasive instruments, as the cost of low-protein animal feeding is relatively low (apart from the cost in training and capacity building).

Low-emission storage, handling and application techniques for animal manure have been discussed for over a century (e.g., Erisman, 2000), and a large amount of convincing experimental evidence has been collected about the effectiveness of these techniques and measures (e.g., Burton and Turner, 2003; Web et al., 2003; Kuczybski et al., 2005; Rotz, 2004). In the EU-27, these techniques and measures are implemented on large pig and poultry farms in the EU-27 through the IPPC Directive (so-called IPPC farms), and described extensively in Reference Documents (European Commission, 2003). The Guidelines for ammonia abatement developed by the Working Group on Ammonia Abatement of the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP) also provides detailed instructions, and various Member States do recommend and/or enforce these techniques and measures in practice. However, these measures and techniques require capital investments and are therefore rather costly. The measures will decrease N losses from animal manure and have the potential benefit of replacing fertilizer N and thereby decreasing N losses associated with N fertilizer production and use. Anaerobic digestion of the animal manure during storage has the additional advantage of producing CH_4 to be used as biofuel. It encompasses the perspectives of minimizing emissions of odours, NH_3, N_2O

and CH_4 during storage, and minimizing emissions of N_2O following application to land. The effectiveness of the manure as N fertilizer is also increased following application of the digested manure to land, but the digested manure has to be injected in the soil to minimize NH_3 losses following application (e.g., Burton and Turner, 2003).

Summarizing, the following set of measures have been selected as most promising measures for mitigating emissions of ammonia, nitrate, phosphorus, nitrous oxide, methane and carbon dioxide from agricultural systems:

(i) Improving N use efficiency in animal production and lowering the N excretion of livestock through low-protein animal feeding, improved herd management and genetic improvement of the herd;

(ii) Improving N use efficiency in crop production and lowering N input in agriculture through balanced N fertilization and improved crop and soil management; and

(iii) Combination of (i) and (ii) plus enforced implementation of technical measures to decrease NH_3 emissions.

These measures are further described below in Chapters 3, 4 and 5

3. Lowering Nitrogen excretion by animals through low-protein feeding

3.1. Introduction

Nitrogen excretion by animals (N-excretion) is usually defined as follows:
N-excretion = N-intake – N-yield in animal products
All N excreted via urine, faeces, skin, sweet, etc., could be considered as N-excretion. A certain N-excretion is necessary as it is related to the maintenance of the animals. With increasing animal performances, the N-intake and N-excretion per animal increase, but the N-excretion per animal product (e.g. milk or meat) decreases. Depending on animal species, the (animal feed) management of the animal and its performance, roughly between 60 and 90 % of consumed N is excreted via urine and faeces (Flochowsky and Lebzien, 2005; Jondreville and Dourmad, 2005; Mateos et al., 2005; ERM/AB-DLO, 1999).

Improving the efficiency of N utilisation at the animal level requires genetic improvement of the herd, a better description of feed, and higher quality feed (e.g. Bichard, 2002; Powell and Norman, 2006; Shook, 2006; Brotherstone and Goddard, 2005). The first limitation for animal production and an efficient utilization of feed protein is an adequate supply and intake of feed (energy). Ruminants are well equipped to convert low quality feeds into valuable products for humans. To exploit the full potential of ruminants, their microbial ecosystem should be adequately fed first. For free ranging animals like non-dairy cattle, sheep and goats this is hardly feasible, but for stall fed ruminants microbial fermentation in the rumen can be optimized by appropriate supplementation with rumen degradable protein, but also minerals and trace elements. To optimize the rumen microbial system, feeds must be characterized according to their ingestive and degradation behavior in the rumen. Characterization of the feed at animal level should subsequently be in terms of (ketogenic, aminogenic and glucogenic) nutrients rather than in terms of digestible organic matter (DOM) or Metabolisable Energy (ME).

This chapter explores the potentials of lowering the N excretion through improving the animal feeding and the animal performance on the basis of the current input data in RAINS/GAINS (because RAINS/GAINS is the official modeling tool and database used for assessing the total NH_3 emissions in EU-27) and against the background of animal physiological and technical possibilities and feasibilities. It provides an overview of the current input data (activity data) in RAINS/GAINS. It also explores the options for lowering the N excretion. Emphasis is on the main animal categories (i) dairy cattle, (ii) other cattle, (iii) pigs and (iv) poultry, as these animal have by far the greatest share in the total NH_3 emissions in EU-25+.

3.2. Nitrogen excretion of main livestock categories.

Table 1 presents the N excretion data for dairy cattle, other cattle, pigs, laying hens and broilers, according to RAINS (Amann et al., 2006a, 2006b). Average values for the EU-25+ are shown at the bottom of the table. Also absolute and relative values for standard deviations per animal category are presented, as a measure of the variation in listed values between countries. Relative differences are largest (>20%) for dairy cattle, other cattle and broilers and smallest (<12%) for pigs and laying hens. Differences between countries for dairy cattle are also shown in Figure 1.

Table 1. Mean N excretion of dairy cows, other cattle, pigs and laying hens, in kg per animal per year, for the year 2000, according to the RAINS database (after Amann et al., 2006a,b).

	Mean N excretion, kg per animal per year				
Country	**Dairy cows**	**Other cattle**	**Pigs**	**Laying hens**	**Broilers**
AT	89.4	45.8	9.0	0.7	0.4
BG	66.5	45.0	12.4	0.8	0.7
BL	108.0	50.0	11.1	0.7	0.5
CR	55.0	45.0	12.4	0.8	0.7
CY	107.6	40.0	12.4	0.8	0.7
CZ	100.3	45.0	12.4	0.8	0.6
DE	113.9	41.0	11.9	0.7	0.5
DK	125.3	37.2	9.6	0.7	0.5
EE	91.0	45.0	12.4	0.8	0.5
EL	63.4	45.0	11.5	0.8	0.7
ES	96.2	35.5	9.6	0.8	0.6
FI	99.3	53.0	10.1	0.8	0.4
FR	100.0	50.0	12.2	0.8	0.9
HU	121.0	45.0	8.9	1.5	1.5
IR	85.0	45.0	12.4	0.8	0.5
IT	108.8	46.9	11.5	0.7	0.5
LT	70.0	50.0	12.4	0.8	0.5
LU	107.6	42.0	9.9	0.8	0.7
LV	71.0	51.0	10.0	0.9	0.9
MT	99.3	40.0	12.4	0.8	0.7
NL	126.2	40.0	9.2	0.7	0.6
PL	75.9	35.0	11.1	0.7	0.6
PT	87.6	49.9	9.1	0.6	0.9
RO	55.0	45.0	12.4	0.8	0.7
SE	120.0	39.0	11.0	0.6	0.3
SI	105.5	40.1	11.9	0.7	0.5
SK	81.9	45.0	12.4	0.8	0.7
TK	55.0	45.0	12.4	0.8	0.7
UK	106.0	49.0	12.4	0.9	0.7
Average	92.8	44.3	11.3	0.8	0.6
St. dev.	21.5	4.7	1.3	0.2	0.2
St. dev. (%)	23	11	12	20	34

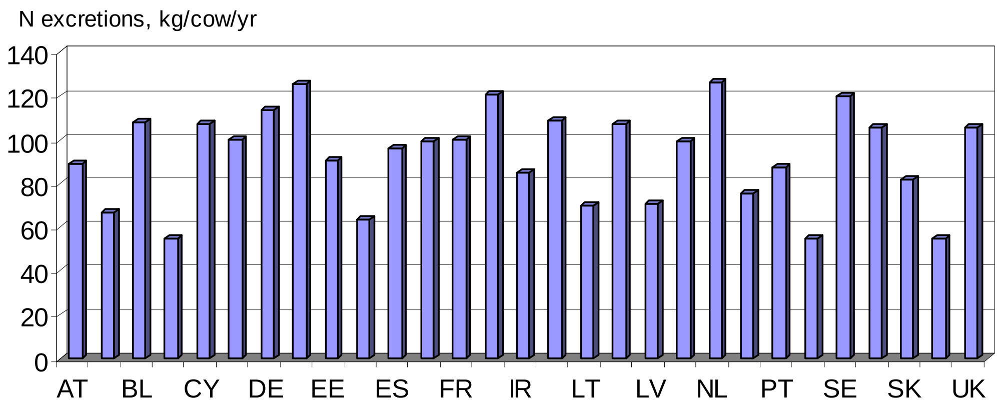

Figure 1. Mean N excretion by dairy cows in countries of the EU-25+ in the year 2000. Note that the order of the countries is similar as in Table 1, but that 'even' countries are not mentioned in the x-axis. Data from RAINS (Amann et al., 2006a).

3.3. Milk yield of dairy cows

Table 2 presents the milk yield of dairy cows for the period 1990-2030 according to RAINS (Amann et al., 2006a, 2006b). Average values for the EU-25+ are shown at the bottom of the table. Also absolute and relative values for standard deviations per target year are presented, as a measure of the variation in milk yield values between countries. Relative differences tend to decrease over time, i.e., differences between countries in milk yield tend to become smaller. The last column presents the projected relative increase in milk yield between 2000 and 2030. Average relative increase is 37%, equivalent to 1.2% per year. The average relative increase for 1990-2000 was 25%, equivalent to 2.5% per yr (not shown).

Table 2. Mean milk yield of dairy cows in kg per animal per year, in the period 1990-2030, according to the RAINS database. Data for Bulgaria (BG), Crotia (CR), Romania (RO) and Turkey (TR) are not from the RAINS database (own estimations).

	Milk yield per dairy cow per country (1990-2030), kg/yr									Δ2030-2000
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	%
AT	3791	4619	5210	5646	6196	6611	6685	7050	7100	36
BG	3000	3000	3000	3300	3500	4000	4500	5000	5000	67
BL	4285	4958	5502	5967	6200	6400	6700	6900	7000	27
CR	3000	3000	3000	3500	4000	4500	5000	5500	5500	83
Cy	4868	5041	6106	5600	5500	5700	6000	6200	6400	5
CZ	3941	4245	5412	6068	6300	6600	6900	7200	7500	39
DE	5200	5500	6122	6439	6600	7000	7300	7500	7700	26
DK	6248	6657	7421	8156	8300	8500	8600	8700	8800	19
EE	4232	3666	4960	6509	6700	6850	7000	7150	7300	47
EL	2509	3181	3055	3184	3300	3500	3800	4200	4500	47
ES	3486	5002	5317	5893	6000	6250	6500	6700	7000	32
FI	5713	6161	6990	7590	8232	8979	9631	9631	9631	38
FR	4723	5517	5948	6548	6700	7000	7300	7500	7700	29
HU	5082	5050	5699	6116	6500	6700	7000	7300	7500	32
IR	4192	4549	4724	4563	4796	5041	5300	5550	5800	23
IT	3795	5195	5790	5489	5800	6200	6500	6800	7200	24
LT	2800	3011	3466	2996	3400	3800	4300	4600	5000	44
LU	4285	4958	6103	6476	6600	6900	7200	7400	7600	25
LV	3437	3074	3898	4250	4400	4700	5000	5000	5000	28
MT	3871	3917	5535	5434	5600	5800	6000	6100	6200	12
NL	6010	6580	7296	7340	7768	7984	8199	8424	8649	19
PL	3246	3230	3668	4340	5000	5600	6000	6500	6900	88
PT	3797	4419	5627	5769	5800	6000	6200	6400	6600	17
RO	3000	3000	3000	3300	3500	4000	4500	5000	5000	67
SE	6086	6853	7710	8051	8200	8350	8500	8600	8700	13
SI	3200	3392	4335	5554	5700	5900	6200	6400	6600	52
SK	2694	3077	4491	4783	5250	5658	5658	5658	5658	26
TR	3000	3000	3000	3300	3500	4000	4500	5000	5000	67
UK	5151	5397	5978	6343	6708	7065	7422	7778	8135	36
Average	4091	4457	5116	5466	5726	6055	6358	6612	6782	37
St. dev.	1084	1236	1412	1483	1484	1452	1409	1333	1346	21
St.dev. (%)	26	28	28	27	26	24	22	20	20	57

3.4. N excretion of dairy cows as function of milk yield and feed management.

Dairy cows have the largest amounts of N in the excrements (dung and urine), while there are also relative large differences in the estimated mean N excretion per country (Table 1, Figure 1). The N excretion of the dairy cows depends on the amount of N in the diet and the amount of N retained in milk and liveweight gain (meat), in formula

$$N_{excretion} = N_{diet} - N_{retained} \qquad [1]$$

Ideally the amount of N in the diet depends on the energy and nutrients requirements of the dairy cows, and most countries have their own criteria and formula for estimating the mean amount of N in the diet. In practice feeding above N requirements may occur, either because producers apply a safety margin or because relatively cheap dietary ingredients have a surplus of N. This is for instance in the case in young leafy grass. The European Commission has proposed to use the following simple formula, based on ERM/AB-DLO (1999).

$$N_{excretion} = [(a * \text{metabolic weight} + b * \text{milk yield}) * \text{N content diet}] - N_{retained} \qquad [2]$$
$$N_{retained} = (\text{milk yield} * \text{N content milk}) + (\text{liveweight gain} * \text{N content liveweight}) \qquad [3]$$

The term "*a * metabolic weight*" represents the feed need for maintenance (metabolic weight is weight$^{0.75}$), while the term "*b* milk yield*" represents the feed need for milk production. As the maintenance need is related to the weight of the animal and that for production to the milk production, the total feed need expressed per liter of milk produced will decrease as the milk production increase. This is a general observation, and underpinned by theoretical and practical evidence, although it must be stated that the feed need for maintenance slightly increases with an increase in milk production (this latter is however not included in the formula). Table 3 provides some estimates for the various coefficients and parameters.

Table 3. Coefficients for estimating the N excretion of dairy cows as function of energy requirement for maintenance and production, protein content of the diet and the amount of N retained by the dairy cows in milk and liveweight gain (after ERM/AB-DLO, 1999).

Coefficients	**Average**	**Lower estimate**	**Upper estimate**
Weight dairy cow, kg	550	400	650
Metabolic weight, kg	114	89	129
Maintenance coefficient 'a', g/day	52	45	60
Milk yield, kg/yr	5.500	3.000	10.000
Production coefficient 'b', kg/kg	0.5	0.44	0.6
Protein content of diet, %	16	13	20
Protein content of milk, %	3.4	3	4
N content of protein in diet, %	6.25	6.25	6.25
N content of protein in milk, %	6.39	6.39	6.39
N retained in liveweight gain, kg	1.5	0.5	3

Using Equation [1] and the coefficients presented in Table 3, the possible relationships between milk yield per dairy cow and N excretion was explored. The results are presented in Figure 2 for a milk production of 3000 to 8000 kg per cow and year, a weight of dairy cows of 450 (for Jerseys) and 650 kg (for Holstein Frisians), a maintenance coefficient of 45 to 60 g feed dry matter per kg MBW per day, a production coefficient of 45 to 60 g dry matter per kg milk, a protein content of the animal feed of 14 to 18%, and a protein content in the milk of 3.5 % and a N retained in liveweight gain (young born calf) of 1.5 kg (Lapierre et al., 2005)

The intercept ranges from 37 kg per cow per year for low-weight cow and a low maintenance coefficient of 45 g per day per kg metabolic weight (representative for year-round housing) and a low protein content in the diet (14%), to a high value of 75 kg per cow per year for high-weight cow and a high maintenance coefficient of 60 g per day per kg metabolic weight (grazing, much walking) and a relatively high protein content in the diet (18%).

The regression coefficient ranges from 0.0054 kg N per kg milk for a low-weight cow and a low production coefficient of 0.45 kg per kg milk (representative for high-quality feed) and a low protein content in the diet (14%), to a high value of 0.0107 kg N per kg milk for high-weight cow and a high production coefficient of 0.60 kg per kg milk (representative for low quality feed) and a relatively high protein content in the diet (18%).

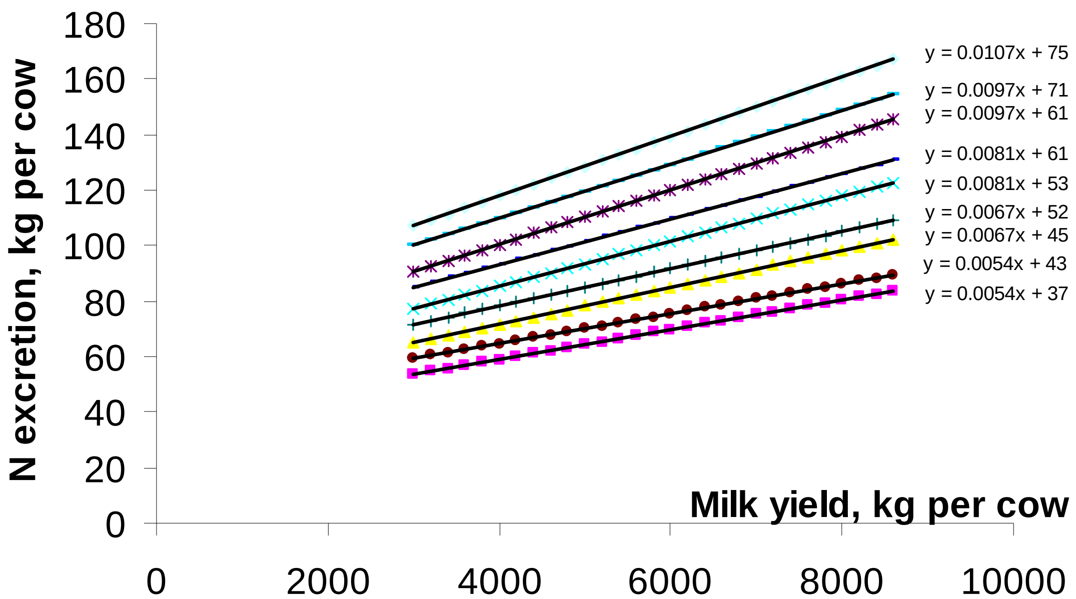

Figure 2. Nitrogen excretion by dairy cows as function of milk yield per cow, maintenance and production coefficients, and N retention. Result of sensitivity analyses using Equation [1] and coefficients from Table 3 (see text).

Evidently, there is a wide range of possibilities but some combinations are more plausible than others. For example, a low-weight dairy cow with a high milk production seems attractive from the point of view of low N excretion, but is not realistic. The combination of low maintenance and production coefficients, a high milk yield per cow and a low protein content in the diet is also attractive from the point of view of low N excretion, but low maintenance and production coefficients can only be realized with high quality feed, a productive herd and good management, and with not too-low protein contents in the diets. On the other hand feed requirements are primarily determined by energy rather than protein requirements. A surplus of protein as compared to energy is 'a waste', because surplus protein is then used as a source of energy and the N included in such energy is wasted.

Deleting the less practical combinations results in a set of four lines, indicating the most likely ranges of N excretion as function of milk production (Figure 3). These regression equations include the default values of ERM/AB-DLO (1999) for the linear relationship between milk yield per cow and N excretion per cow, with an intercept of about 50-60 kg N/yr and a regression coefficient of 0.007-0.009 kg N per kg milk.

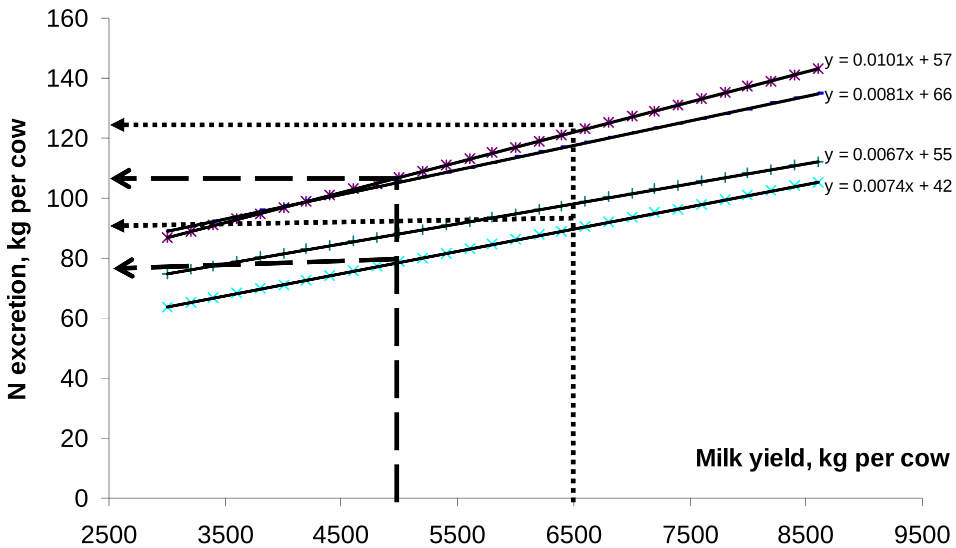

Figure 3. Most likely ranges of N excretion (kg N/yr) by dairy cows producing an average of 5000 kg per cow per year in 2000 (mean 95; range 75-105) and an estimated average of 6500 kg per cow per year in 2020-2025 (mean 110; range 95-125).

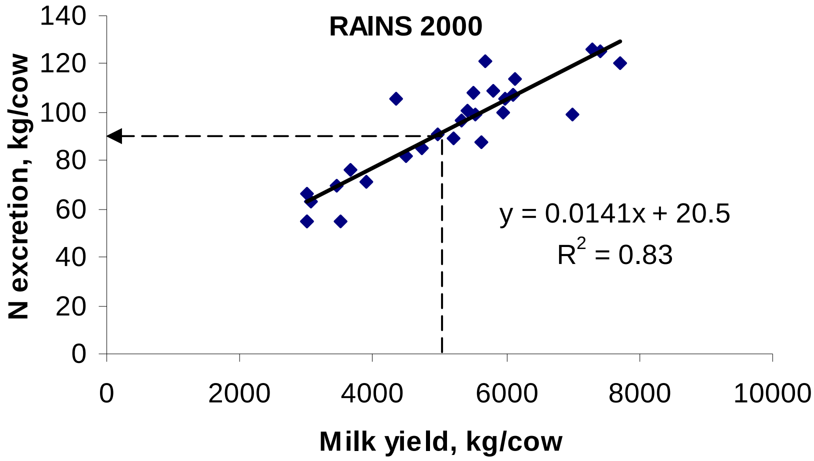

Figure 4. Relationship between N excretion by dairy cows and milk yield per cow in the countries of EU-25+ for the year 2000, according to the RAINS database (Amann, 2006a, 2006b).

The relationship between milk yield and N excretion of dairy cows according to the data of the RAINS data base for the year 2000 are shown in Figure 4. There is a clear linear relationship with a high correlation (r^2 = 0.83), suggesting that milk yield explains 83% of the variation in mean N excretion of the dairy cows between countries, and that the other variables explained in Table 3 contribute only 17% to the variation. Further, the intercept of the linear relationship is relatively low and the regression coefficient relatively high. This combination of unusual low intercept and unusual high regression coefficient may suggest different populations, with small, low-yielding but relatively efficient dairy cows at the lower end and large, high-yielding, but relatively inefficient dairy cows at the higher end of the curve.

3.5. Prospects of lowering N excretion of dairy cows.

The subject of reducing N excretion in dairy and beef cattle was recently reviewed by Flachowski and Lebzien (2005). The important principles to reduce N-excretion in ruminants are given in Table 4. It is important to distinguish in N-excretion per animal and per kg of milk produced. The objective of animal feeding should be to meet the N-requirements of rumen microorganisms and ruminants depending on animal species, categories and performances to keep the animal healthy and to reduce N in manure. From these the following recommendations can be given:

- A sufficient and continuous energy and nitrogen supply of the microbes in the rumen is most important (microbial fixation of N in the rumen)
- Avoidance of excess N-intake
- Protected proteins (UDP) are adequate, if an increase of microbial protein synthesis fails to meet utilizable protein requirements (insufficient energy intake)

Table 4: Principles to influence N-excretion in ruminants (after Flachowski and Lebzien, 2005)

Measure	**N-excretion per animal**	**N-excretion per kg milk**
Lowering N-excess in feeding	↓	↓
Increase of animal performance	↑	↓
Shorten growing period for reproduction of cows	↓ ≈	↓
Increase productive life of cows	↑	↓
Improved microbial protein synthesis	↓ ≈	↓
Synchronisation of energy and protein degradation in the rumen	≈ ↓	≈ ↓

↑ Increase ↓ Decrease ≈ No significant influence

The relationship between milk yield and N excretion for the year 2000 according to the RAINS database (Figure 4) suggests that milk yield is a very strong indicator for the N excretion of dairy cows according to this database, and also that the mean excretion at a suggested mean milk production of 5000 kg per cow per year in EU-25 is 90 kg per cow per year. This amount falls within the lower half of the realistic range derived in Figure 3, suggesting that the protein content of the animal feed in practice is modest (rather low) according to the RAINS database. This result contrasts with the results of the CAPRI database and of some other reports that suggest that the N excretion of cattle can be lowered significantly through low protein feeding. This discrepancy could result from a lack of reliable real information on feed and N intake and the subsequent assumption that intake is equal to meeting feed requirements. Meeting energy requirements may be good approximation of energy intake, for protein intake this is not necessarily the case.

In theory, the mean N excretion of cows producing 5000 kg milk per year could be lowered maximally by about 10 kg (from 90 to 80 kg per cow per year), by lowering the protein content of the animal feed by 1.5% (from for example 16 to 14.5%). This would require a relatively large proportion of (silage) maize in the diet of the dairy cows and or low protein grass (silage). This would require subsequently a considerable extension of the area of silage maize in the EU-25+ at the expense of grassland, and or changes in grassland management (less N fertilization and grazing, harvesting silage at harvest of >4000 kg per ha). An alternative would be to balance the protein content of the diet by concentrates with appropriate protein content. Hence, lowering of the protein content of the animal feed of dairy cattle would be possible, but very likely by not more than about 10%.

Another option for decreasing N excretion is the following. Milk production is suggested to increase in the next decades by slightly more than 1% per year reaching an average level of 6500 kg per cow per year by 2020/2025 (Table 2). The estimated mean N excretion is 110 kg in 2020/2025, with a range of 95-125 kg per cow per yr. When assuming that the total milk production in EU-25+ remains constant, it will be clear that 30% less cows are needed to produce the same quantity of milk, and that the total N excretion will decrease by 11% (additional effects of less replacement cattle not included yet). Increasing the milk production further to 7500 kg per cow per year (which is possible) would decrease the total N excretion by another 5% per year. Hence, increasing the milk production per cow decreases the N excretion per liter milk produced (because the maintenance cost of the dairy herd decreases), and thereby is an effective measure for improving the N use efficiency at the herd level.

Currently, there is a milk quotum in the EU, and on the basis of a fixed milk quotum per country, one would expect a strong relationship between the increase in milk production per cow and the decrease in the number of dairy cattle. However, the relationships that may be derived from a fixed milk quota in the EU (inverse relationships between the number of dairy cattle and the milk production per dairy cow), may not be consistent over time (i.e. for time horizons 2010 and 2020), according to Zig Klimont (personal communication, December 2006), because the estimations of the number of dairy cows and the projected increases in milk production may have been derived independently for some countries. Table 5 presents the number of dairy cows and other cattle per country for the year 2000 and country specific projections for the years 2010 and 2020, according to the RAINS database (National Projections). Also the mean change in number of cattle (in per cent per year) for the periods 2000-2010 and 2010 and 2020 are presented. The total number of dairy cows in all countries will decrease by on average 1.3% (range: decrease of 2.2% versus increase of 2.8%) per year in the period 2000-2010 and by on average 0.5% (range: decrease of 1.5% versus increase of 2.4%) in the period 2010-2020. The total number of other cattle in all countries will decrease by on average 0.9% (range: decrease of 2.7% versus increase of 4.3%) per year in the period 2000-2010 and by on average 0.3% (range: decrease of 5.8% versus increase of 3.3%) in the period 2010-2020. The change of the number of other cattle is related to the change in the number of dairy cattle (see Figure 5; less replacement cattle needed).

A comparison of the changes in average milk yield per cow per country and the change in number of dairy cows per country for the periods 2000-2010 and 2010-2020 is shown in Figure 6. There is indeed some inverse relationship, but the scatter is very large. The scatter is larger for the period 2010-2020 than for the period 2000-2010, probably because some countries have anticipated on a possible abolishment of the milk quota regulation by the year 2025. On average, the relative increase in milk production per cow is larger than the relative decrease in the number of animals. This is especially true for the period 2010-2020. This would suggested that the total milk production will increase slightly in the EU by about 0.1% per year in the period 2000-2010 and by 0.8% per year in the period 2000-2020.

Table 5: Number of dairy cattle and other cattle per country in the years 2000, 2010 and 2020, and relative changes in the number of dairy cattle and other cattle for the periods 2000-2010 and 2010-2020, calculated on the basis of data of the RAINS

database. Note that Turkey is included in this inventory (after Amann et al., 2006a, 2006b).

	Number of dairy cows (x1000)			Change, in % per year per period		Number of other cows (x1000)			Change, in % per year per period	
Country	2000	2010	2020	2010-2000	2020-2010	2000	2010	2020	2010-2000	2020-2010
AT	621	516	488	-1.7	-0.6	1534	1425	1409	-0.7	-0.1
BG	431	357	316	-1.7	-1.1	251	296	361	1.8	2.2
BL	629	514	503	-1.8	-0.2	2372	2338	2083	-0.1	-1.1
CR	255	240	240	-0.6	0.0	172	246	326	4.3	3.3
CY	24	21	21	-1.3	0.0	30	29	27	-0.4	-0.7
CZ	611	550	550	-1.0	0.0	998	850	850	-1.5	0.0
DE	4564	3876	3338	-1.5	-1.4	10004	8885	8878	-1.1	0.0
DK	636	528	466	-1.7	-1.2	1232	1028	905	-1.7	-1.2
EE	131	112	117	-1.4	0.5	122	139	105	1.4	-2.4
EL	180	148	126	-1.8	-1.5	386	384	394	0.0	0.3
ES	1139	1000	878	-1.2	-1.2	4935	4668	4415	-0.5	-0.5
FI	364	285	258	-2.2	-0.9	693	559	233	-1.9	-5.8
FR	4203	3691	3691	-1.2	0.0	16108	15454	15454	-0.4	0.0
HU	370	306	285	-1.7	-0.7	435	551	622	2.7	1.3
IR	1174	1034	922	-1.2	-1.1	5384	4423	4015	-1.8	-0.9
IT	2065	1802	1776	-1.3	-0.1	5180	5122	4642	-0.1	-0.9
LT	494	473	436	-0.4	-0.8	404	314	329	-2.2	0.5
LU	44	40	36	-0.8	-1.2	156	152	153	-0.3	0.1
LV	205	180	175	-1.2	-0.3	162	186	175	1.5	-0.6
MT	9	8	8	-1.2	0.0	91	93	93	0.3	0.0
NL	1504	1395	1725	-0.7	2.4	2566	2097	1781	-1.8	-1.5
PL	2982	2450	2150	-1.8	-1.2	2741	2600	2700	-0.5	0.4
PT	252	322	279	2.8	-1.3	920	1005	977	0.9	-0.3
RO	1692	1523	1505	-1.0	-0.1	1359	1350	1350	-0.1	0.0
SE	428	380	380	-1.1	0.0	1256	1075	1075	-1.4	0.0
SL	140	124	114	-1.1	-0.8	353	396	413	1.2	0.4
SK	243	206	197	-1.5	-0.4	404	488	496	2.1	0.2
UK	2336	1909	1909	-1.8	0.0	8798	6408	6408	-2.7	0.0
Total	**27725**	**23988**	**22888**	**-1.3**	**-0.5**	**69044**	**62561**	**60670**	**-0.9**	**-0.3**

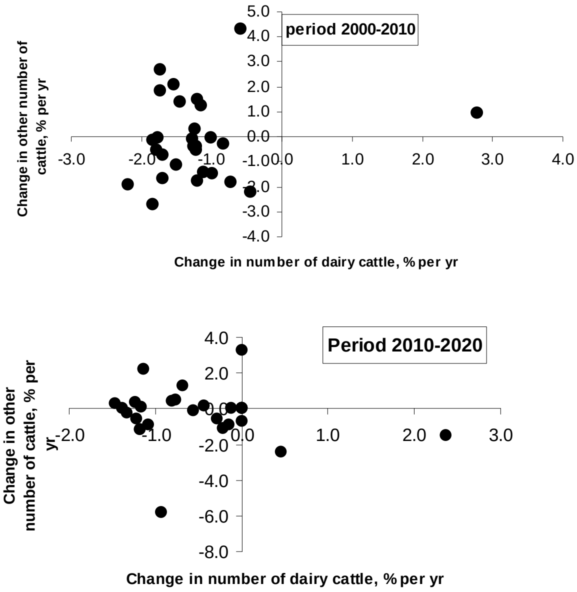

Figure 5. Relationship between the relative change in the number of dairy cattle per country (in % per yr) and the relative change in the number of other cattle per country (in % per year) for the periods 2000-2010 (upper panel) and the period 2010-2020 (lower panel).

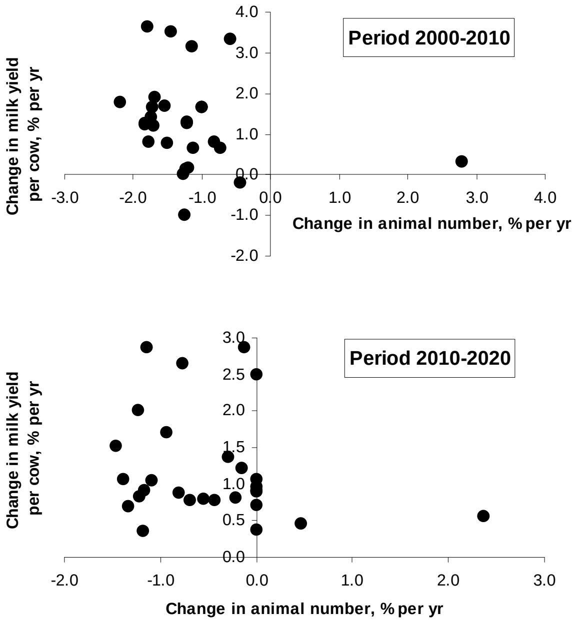

Figure 6. Relationship between the relative change in the milk yield per cow per country (in % per yr) and the relative change in the number of dairy cows per country(in % per year) for the periods 2000-2010 (upper panel) and the period 2010-2020 (lower panel). A relative strong increase in number of dairy cattle is projected for Portugal (2000-2010), and for the Netherlands in the period 2010-2020 (because of the expected abolishment of the milk quota regulation).

Summarizing, the N excretion of dairy cattle in EU-25 may be lowered on average by 10% through lowering the protein content of the animal feed during the next 15-20 years. The expected increase in milk production per cow and hence the resulting decrease in number of dairy cows (and replacement cattle) has already been taken into account in the baseline scenario of the RAINS database, though there is a large scatter in the relationship between the relative increase in milk production and the relative decrease in the number of dairy cows due to differences between countries. However, the expected average increase in milk production per cow per year (1.3% per year, equivalent to 50-70 kg per cow per year) during the next decades is very modest. For example, the average increase in milk production per cow per year during the period 1995-2000 was much higher (2.9% per year, equivalent to 130 kg per cow per year). Hence, there is scope for a stronger (further) increase in milk production per cow, and such stronger increase will be beneficial from the viewpoint of the farmer (less cows and animal feed needed to produce the target milk quantity) and from the viewpoint of the environment (less N excretion and NH_3 emission per kg milk produced). However, it will require education and training, improving the genetic potential of the herd, and proper economic incentives.

On the basis of this analysis, it is fair to say that the total N excretion of dairy cattle can be lowered in the next 15-20 years by some ~ 10% by a combination of low-protein feeding and a slightly stronger increase in milk production per cow than predicted by the RAINS database. The ~10% decrease in total N excretion by dairy cattle translates in a proportional decrease in the emission of NH_3; hence in a decrease in the emission of NH_3 from dairy cattle of ~10%.

3.6. Nitrogen excretion by other cattle as function of feed management

The category 'other cattle' in Europe includes replacement cattle and fattening cattle. It is a broad variety of cattle and includes:

- replacement cattle, < 1 year;
- replacement cattle, > 1 year;
- fattening calves <0.5 year;
- fattening bulls 0.5-1.5 year
- suckling cows > 2 years
- other fattening cattle <1 year
- other fattening cattle >1 year

The number of other cattle has increased in EU-15 following the implementation of milk quota in the 1980s, and the subsequent decrease in dairy cattle, because some farmers switched to fattening cattle and suckling cows. Currently the number of other cattle is larger than the number of dairy cattle, but N excretion per animal is much smaller. According to the RAINS database, the average N excretion is 44.3 kg per year per animal in EU-25, with a surprisingly small variation between countries (range 37-53; standard deviation is 4.7 kg per animal per year ; Table 1).

The N excretion of other cattle depends on the amount of N in the diet and the amount of N retained in liveweight gain (meat), in formula

$N_{excretion} = N_{diet} - N_{retained}$ [1]

The amount of N in the diet depends on the energy and nutrients requirements of the cattle, and most countries have their own criteria and formula for estimating the mean amount of N in the diet. The following simple formula can be used to calculate the N excretion (ERM/AB-DLO, 1999):

$N_{excretion} = [(d * \text{liveweight gain}) * \text{N content diet}] - N_{retained}$ [2]

$N_{retained} = (\text{liveweight gain} * \text{N content liveweight})$ [3]

The coefficient "*d*" represents the feed conversion ratio, i.e. the amount of feed needed to increase liveweight gain by 1 kg. The feed conversion ratio increases with the age of the cattle. Young veal calf have a low feed conversion coefficient (~5), while fattening cattle > 2 years have a high feed conversion coefficient (~15). The reverse is true for the N retention, i.e. the protein retention and requirements per kg of gain decrease with the age of growing cattle. However, in order to maintain a proper microbial fermentation in the rumen, the N requirements for the microbial population in the rumen have to be met and dietary crude protein (Nx6.25) content should not be lowered to less than ~12 %.

Table 6 provides estimates of the N excretion of other cattle. The N excretion greatly depends on the age of the cattle (energy requirement) and on the protein content of the animal feed. Lowest N excretion is for veal calves and the largest N excretion by suckling cows and cattle at the age of 1-2 yr. Apart from suckling cows, most other cattle is less than 2 years old. On dairy farms, the replacement rate is usually between 30 and 40%, indicating that 60 to 70% of the calves of dairy cows are fattened, especially the males. The number of suckling cows in EU-25+ tends to increase (extensive grazing).

Table 6. Nitrogen excretion by other cattle. For each category upper and lower estimates are provided.

Cattle category	**Average**	**Lower estimate**	**Upper estimate**
Replacement cattle, category < 1 yr;	30	25	45
Replacement cattle, category > 1 yr;	60	40	80
Fattening calves <0.5 year;	15	10	30
Fattening bulls 0.5-1.5 year	35	30	50
Suckling cows > 2 years	70	50	90
Other fattening cattle <1 year	35	30	50
Other fattening cattle >1 year	60	40	80

The protein content of the animal diet is in the range of 12 to 20% (N content in the range of 21 to 33 g/kg) and greatly depends on the grazing system and on the feeding with silage maize. On some farms, fattening cattle including bulls and oxen are grazing for the greater part of the year on pastures (relatively high protein content), while fattening bulls on other farms are kept in cubicle houses all year round and fed with a large proportion of silage maize in the diet (relatively low protein content).

Comparing the average N excretion for other cattle according to RAINS (~44 kg per animal per year; Table 1) with the data presented in Table 6 suggests that the N excretion for other cattle in the RAINS database is not (excessively) high. The higher values for some countries may indicate the presence of a relatively large percentage of suckling cows and/or animal diets relatively rich in protein. Hence, the scope of decreasing the protein content of the diet of other cattle seems to be modest, when assessed on the basis of the N excretion values of the RAINS database. The results suggest that the mean N excretion may decrease by (maximally) 10%, through a decrease of the protein content of the animal feed and a more adjusted feeding, during the next 15 to 20 year (2020/2025 as horizon). For grazing cattle this may not be feasible, because the animals select forage with the highest protein content. However, above an age of 1 yr, over 80% of the ingested N is lost in maintenance and excreted. This can be reduced by make them growing faster so that the fattening period can be shortened. This could be achieved by supplementing the diet with (low protein) concentrates. However, this possible decrease that seems achievable with beef cattle is likely off-set by a larger feed requirement of the replacement cattle, because of the tendency to shift from small breeds to larger breeds for dairy cows. Hence, the prospects for decreasing the protein content of the animal feed of other cattle are very modest when evaluated on the basis of the data in RAINS.

Another possible option would be to lower the replacement rate of dairy cows from 40% to 30%, though improved management of the dairy herd, and to slaughter the fattening cattle at younger age. Lowering the replacement rate of dairy cattle will be difficult because of a usually observed inverse relationship between milk yield and fertility. A further option could be to make the replacement animals grow faster and let them calve at an earlier age, for instance at 22 rather than 24 months. The first option is financially attractive for dairy farmers, because raising young stock is rather expensive. However, lowering the replacement rate requires improved management and information. The latter option will have major consequences for the sector involved.

The number of other cattle is expected to decrease in the next decades by on average 0.9% per year during the period 2000-2010 and by 0.3% per year during the period 2010-2020 according to the RAINS database (Table 5). This decrease is in line with the expected decrease in dairy cows (less replacement cattle is needed). However, the relationships between the relative decrease in the number of dairy cattle and the relative decrease in the number of other cattle is highly scattered (Figure 5), suggesting that the expected decrease in the number of other cattle is not related to the decrease in the number of dairy cattle. The changes in the number of other cattle will also depend on the response of the farmers to the CAP reform, in particular to the decreases in the premiums on beef and veal, and on the development of world market prices, in particular the development of the beef industry in (Latin) America.

Summarizing, there is some scope of lowering the total N excretion of other cattle in EU-25 through a combination of:

- a lower replacement rate of dairy cattle

- a faster growth rate and lower age of calving (from 26-24 to 22 months) of the dairy replacement cattle; and
- low-protein feeding of the other cattle.

This package of measures may lead to a decrease of the N excretion of other cattle in EU-25 by some 5-10% during the next 15-20 years. This indicates that the scope for decreasing the N excretion is modest.
The evolution of the total N excretion of other cattle also depends on the response of farmers to the CAP reform and to the Rural Development Regulations, especially as regards the involvement of other cattle in grazing. The projected changes in the number of other cattle show a small decrease over time, but this decrease is uncertain.

3.7. Nitrogen excretion of pigs

The category 'pigs' includes (rearing) sows, piglets, (rearing) boars and fattening pigs. The number of pigs in EU-25 has steadily increased over the last couple of decades, and the current number is about 150 million. The number of pigs may drop and increase shortly thereafter again, due to the incidence of diseases and changes in markets.

Projections of the number of pigs for 2010 and 2020 according to the RAINS database suggest very little change (Table 7). Projections for the periods 2000-2010 and 2010-2020 suggest average changes of -0.2 and +0.1% per year, respectively. Changes in some of the new member states are somewhat larger, but overall a slight but steady increase is expected.

According to the RAINS database, the average N excretion is 11.3 kg per year per animal in EU-25, with a surprisingly small variation between countries (range 8.9-12.4; standard deviation is 1.3 kg per animal per year; Table 1). The average N excretion of pigs depends on the amount of N in the diet, the housing system and the amount of N retained in liveweight gain (meat), in formula:

$$N_{excretion} = N_{diet} - N_{retained} \quad [1]$$

The amount of N in the diet depends on the energy and nutrients requirements of the pigs. The following simple formula can be use to calculate the N excretion (ERM/AB-DLO, 1999):

$$N_{excretion} = [(d * \text{liveweight gain}) * \text{N content diet}] - N_{retained} \quad [2]$$
$$N_{retained} = (\text{liveweight gain} * \text{N content liveweight}) \quad [3]$$

The coefficient "*d*" represents the feed conversion ratio, i.e. the amount of feed needed to increase liveweight gain by 1 kg. The feed conversion ratio increases with the age of the pigs. For fattening pigs (weight 25 to 110 kg), the average feed conversion ratio is in the range of 2.3-3.2 kg per kg (mean 2.8), depending on the management, the addition of antibiotics to the feed and genetic potential. As is the case with growing cattle, N deposition and hence protein requirement decrease with age. As a result, an increasing proportion of dietary N is lost in maintenance. These losses can be minimized by make them grow faster and reduce the length of the fattening period.

Table 7: Number of pigs per country in the years 2000, 2010 and 2020, and relative changes in the number of pigs for the periods 2000-2010 and 2010-2020, calculated on the basis of data of the RAINS database (after Amann et al., 2006b).

	Number of pigs (x1000)			Change, in %	
Country	2000	2010	2020	2010-2000	2020-2010
AT	3348	3215	3228	-4	0
BG	1512	931	931	-38	0
BL	7266	8024	8073	10	1
CR	1233	1257	1273	2	1
CY	408	457	457	12	0
CZ	3315	3800	3800	15	0
DE	27871	27167	25100	-0.3	-0.8
DK	11922	13865	14251	16	3
EE	300	358	448	19	25
EL	1008	1060	1062	0.5	0.0
ES	20035	21049	22129	0.5	0.5
FI	1298	1280	1270	-1	-1
FR	22092	22797	22797	0.3	0.0
HU	4974	4207	5716	-1.5	3.6
IR	1732	1585	1503	-0.8	-0.5
IT	8307	8715	9181	0.5	0.5
LT	849	953	1004	1.2	0.5
LU	142	149	152	0.4	0.2
LV	344	419	420	2.2	0.0
MT	91	93	93	0.3	0.0
NL	13281	11122	11185	-1.6	0.1
PL	6690	7864	8639	1.8	1.0
PT	3161	3119	2944	-0.1	-0.6
RO	5140	5590	5590	0.9	0.0
SE	2400	2838	2838	1.8	0.0
SL	624	700	744	1.2	0.6
SK	1236	1463	1569	1.8	0.7
UK	10439	6535	6535	-3.7	0.0
Grand Total	130414	127424	129201	-0.2	0.1

Table 8. Nitrogen excretion of pigs. For each category upper and lower estimates are provided, in kg per animal place per year.

Cattle category	**Average**	**Lower estimate**	**Upper estimate**
Sows and boars	20	15	25
Sows including piglets till 25 kg	28	22	35
Piglets 6 weeks to 25 kg	3	2	5
Rearing sows and boars	13	11	18
Fattening pigs	11	10	15

Table 8 provides estimates of the N excretion of the various categories of pigs. Lowest N excretion is for piglets weaned at 6 weeks and transferred to fattening pigs at the weight of 25 kg per animal. The protein content of the pig diet is in the range of 12 to 18% (N content in the range of 20 for sows and boars, 25 for fattening pigs and 28 g/kg for piglets; phase-feeding) and greatly depends on the animal feed management (home-grown cereals versus purchased concentrates).

Comparing the average N excretion for pigs according to RAINS (~11.3 kg per animal per year; Table 1) with the data presented in Table 8 suggests that the N excretion for pigs in the RAINS database is not (excessively) high. The higher values for some countries may indicate the presence of a relatively large percentage of sows and boars and/or animal diets relatively rich in protein. The higher percentage of sows and boars could be reduced by an improved fertility.

Recently, the subject of lowering N excretion in pigs was reviewed by Jondrevilla and Dourmad (2005). The results they showed indicate that the protein content of fattening pigs in the range of 17.8 to 13.6% (equivalent to 28 to 22 g N per kg) gave no difference in growth rate and health of the pigs, but large differences in the N excretion per pig. They suggested that two complementary approaches can be used for improving the efficiency of utilisation of N by pigs and, consequently, reduce N excretion. The first approach is to ensure adequate protein and amino acid supplies over time according to the growth potential of the animal or their physiological status. This requires a joint fitting of daily supplies of energy and protein (amino acids) depending on pig potential and stage of production, as well as production objectives. The second approach is to improve dietary amino acid balance and consequently reduce protein content of the diet. This can be obtained through the combination of different protein sources and/or the utilisation of industrial amino acids. Both approaches have been proved to be efficient for reducing N output. However, It must be pointed out that the development of such feeding techniques for reducing N excretion by the pigs requires a good knowledge of amino acid availability in the feedstuffs, and of changes in amino acids requirements according to growing stage or physiological status. This is now within reach with the use of modelling techniques for predicting the requirements, and with a better knowledge of variations of amino acid availability in feedstuffs according to their origin and specific compositional characteristics.

Table 9. Suggested indicative crude protein values as best available technique (BAT), according to the IPPC Reference Document on Best Available techniques for the intensive rearing of poultry and pigs (IPPC, 2003).

Species	Phases	Crude protein content (% in feed)	Remark
Weaner	<10 kg	19 – 21	With adequately balanced and optimal digestible amino acid supply
Piglet	<25 kg	17.5 – 19.5	
Fattening pig	25 – 50 kg	15 – 17	
	50 – 110 kg	14 – 15	
Sow	gestation	13 – 15	
	lactation	16 – 17	

Table 5.1: Indicative crude protein levels in BAT-feeds for pigs

The IPPC Reference Document on Best Available techniques for the intensive rearing of poultry and pigs (IPPC, 2003) provides also recommendations for low-protein feeding of pigs. The suggested indicative crude protein values as best available technique (BAT) have been summarized in Table 9. The highest protein content is required for weaners and piglets (21 to 17.5%), but these animals also have the highest N retention (about 45-50%), because of their fast growing rate. Fattening pigs require 17 to 14 % protein (equivalent to 27 to 22 g N per kg), depending on the growing stage. Fattening pigs have a N retention of about 30-40%, depending on the protein content in the animal feed; the average for EU-15 is about 34%. Sows also require 17 to 14 % protein (equivalent to 27 to 22 g N per kg), depending on the lactation period. The mean N retention of sows is 20-25% (mean of EU-15 about 23%).

Comparison of the results of Jondrevilla and Dourmad (2005) with the indicative crude protein values according to the IPPC Reference Document on Best Available techniques for the intensive rearing of poultry and pigs (IPPC, 2003), suggest that there is still some scope for further decreasing the protein level of pig feed. This is also the notion of experts of the European Animal Feeding Producers Association (FEFAC) and of the Animal Sciences Group of Wageningen University. Based on Jondrevilla and Dourmad (2005) and other experts (Dr Age Jongbloed, personal communication, December 2006), it is reasonable to suggest that the protein content of the pigs, including the suggested indicative crude protein contents according to the BREF of the IPPC (2003) may be lowered by some 10% during the next 10 to 15 years. However, this requires training and support of farmers, as well as the provision of animal feed with the proper amino acids in balance. The cost of low-protein feed (10% less on average) has been estimated at less than 1 euro per pig (Dr. Age Jongbloed, December 2006).

There is one possible future development which may block a possible decrease in the protein content of the animal feed of pigs (and poultry), and that is the projected strong increase in biofuels. The increasing demand for biofuels will compete to some extend with the demand for high-quality animal feed, and it has been suggested that an increasing supply of low-quality byproducts from the production of biodiesel and ethanol will become on the market. These by-products (DDGS) of the biofuel industry are poor in energy and rich in protein and fiber (but have low-quality protein), after the energy has been distilled and removed, and probably will be offered to the animal feed industry as cheap ingredients for animal feed. As a consequence, the protein content of the animal feed may have the tendency to increase in the near future, when these trends become noticeable. The implications for the animal feed industry of the increasing interest in biofuels were recently (19 October 2006) discussed at an international Conference organized by the animal feed industry (www.schothorst.nl), and the concerns raised were confirmed at the first International Ammonia Conference on 19-21 March 2007 (www.firstammoniaconference.wur.nl/).

Summarizing, there is scope for further decreasing the protein content of the pig feed by on average 10% at the cost of less than 1 euro per pig. This holds for pigs that are fed concentrates. Hence, the mean N excretion may decrease by maximally 10% over the next 15 to 20 years (2020/2025 as horizon).

3.8. Nitrogen excretion of poultry

The category 'poultry' includes rearing hens, breeders, layers and broilers. The number of chicken in EU-25 has steadily increased over the last couple of decades, and the current number is about 1.2 billion. The number of chickens drops and increases again from time to time, due to the incidence of diseases and changes in markets.

Projections of the number of poultry for 2010 and 2020 according to the RAINS database suggest little change (Table 10). Projections for the periods 2000-2010 and 2010-2020 suggest average increases of 0.6 and 0.1% per year. Changes in some of the new member states are somewhat larger, but overall a slight but steady increase is expected.

According to the RAINS database, the average N excretion for laying hens is 0.8 kg per year per animal in EU-25, with a range of 0.6 to 1.5 kg per animal place year and a standard deviation of 0.2 kg per animal place per year. The average N excretion for broilers is 0.6 kg per year per animal in EU-25, with a range of 0.4 to 1.5 kg per animal place year and a standard deviation of 0.2 kg per animal place per year (Table 1). The relatively high value (too high?) of 1.5 kg per animal per year for both broilers and laying hens is for Hungary. The high value probably reflects the presence of geese.

The average N excretion of poultry depends on the amount of N in the diet and the amount of N retained in liveweight gain (egg and meat), in formula

$N_{excretion} = N_{diet} - N_{retained}$ [1]

The amount of N in the diet depends on the energy and nutrients requirements of the poultry. The following simple formula can be use to calculate the N excretion (ERM/AB-DLO, 1999):

$N_{excretion} = [(d * \text{liveweight gain}) * \text{N content diet}] - N_{retained}$ [2]

$N_{retained} = (\text{liveweight gain} * \text{N content liveweight})$ [3]

Table 10: Number of poultry per country in the years 2000, 2010 and 2020, and relative changes in the number of pigs for the periods 2000-2010 and 2010-2020, calculated on the basis of data of the RAINS database (after Amann et al., 2006b).

	Number of poultry (x1000)			Change, in %	
Country	2000	2010	2020	2010-2000	2020-2010
AT	11787	13007	13007	10	0
BG	14963	17927	20125	20	12
BL	52230	52754	54005	1	2
CR	11251	11877	12589	6	6
CY	3310	4418	4830	33	9
CZ	32043	34975	36234	9	4
DE	118447	99333	89767	-1.6	-1.0
DK	21830	21770	22326	0	3
EE	2366	2509	2640	6	5
EL	28193	25597	23923	-0.9	-0.7
ES	169133	181534	194844	0.7	0.7
FI	12570	14372	13113	14	-9
FR	270989	249570	226966	-0.8	-0.9
HU	31244	43000	43000	3.8	0.0
IR	15338	13800	13200	-1.0	-0.4
IT	176722	189027	197983	0.7	0.5
LT	6373	9351	12782	4.7	3.7
LU	70	77	86	1.0	1.2
LV	3105	5170	5091	6.7	-0.2
MT	830	1010	1010	2.2	0.0
NL	104972	102320	108629	-0.3	0.6
PL	111900	170200	171500	5.2	0.1
PT	41195	33317	38699	-1.9	1.6
RO	77993	100000	104000	2.8	0.4
SE	16900	20000	20000	1.8	0.0
SL	5107	5488	5552	0.7	0.1
SK	12446	12447	11602	0.0	-0.7
UK	168973	175620	175620	0.4	0.0
Grand Total	1359929	1436861	1444253	0.6	0.1

The coefficient "*d*" represents the feed conversion ratio, i.e. the amount of feed needed to increase liveweight gain by 1 kg or to produce 1 kg of egg. The average feed conversion ratio for egg production is in the range of 1.9-2.6 kg per kg (mean 2.3), depending on the (housing) management, the addition of antibiotics and anti-microbial growth promoters to the feed and genetic potential. The average feed conversion ratio for broilers is in the range of 1.6-2.2 kg per kg (mean 2.0), depending on the management, the addition of antibiotics and anti-microbial growth promoters to the feed, the genetic potential and the weight of the broilers at slaughter and the number of cycles per year (commonly 6 to 10).

Table 11. Nitrogen excretion of poultry. For each category upper and lower estimates are provided, in kg per animal place per year.

Cattle category	**Average**	**Lower estimate**	**Upper estimate**
Breeders (hens and cocks >5 months)	1.0	0.9	1.3
Rearing hens and cocks (<5 months)	0.4	0.3	0.5
Laying hens	0.8	0.6	0.9
Broilers	0.6	0.4	0.9

Table 11 provides estimates of the N excretion of the various categories of poultry. The N excretion greatly depends on the age of the chicken (energy requirement), on the protein content of the animal feed, and on the housing system (batteries versus ground-based systems). Lowest N excretion is for rearing hens and broilers and highest N excretion for the breeders (mother animals).

The protein content of the poultry diet is in the range of 15 to 22% (N content in the range of 23-25 g/kg for layers to 30-35 g/kg for young broilers, with phase-feeding) and greatly depends on the animal feed management (home-grown cereals versus purchased concentrates).

Comparing the average N excretion for layers (~0.8 kg per animal per year) and for broilers (~0.6 kg per animal per year; Table 1) with the data presented in Table 11 suggests that the N excretion for poultry in the RAINS database is not (excessively) high, except for some countries like Hungary. Hence, the scope of decreasing the protein content of the diet of poultry seems to be modest, when assessed on the basis of the N excretion values of the RAINS database.

The potential to reduce N excretion in poultry was reviewed by Matteos et al. (2005). They state that in the past, there has been little pressure to decrease excretion. Hence, in the past poultry producers have typically overfed N and P. The amount of N excreted depends on three major factors: 1) amount of total N that is consumed, 2) the efficiency of their utilization and 3) the amount of endogenous N. Endogenous losses are quite constant under practical feeding conditions and therefore, to reduce excretion the intake has to be lowered and the efficiency of use has to be improved. Poultry diets, specially for meat production, are high in protein due to the high requirements in amino acids for lean growth. However, a portion of this protein is not used either because is not digested or because the pattern of amino acids that are absorbed does not match poultry needs. Amino acids that are in excess of requirements are deaminated and the N portion is excreted in the urine as uric acid increasing pollution. On average, only 40% of feed N is used for production, eggs or meat, and the remainder is excreted. In all cases, N excretion can be reduced by a better balance of amino acids in the diet.

The transfer of N from feed to egg by laying hens is usually below 40%. The efficiency of protein utilization is best when all amino acids are close (not above) to needs for protein accretion and maintenance. Matteos et al (2005) reviewed literature data that indicate that the productive performance of laying hens was similar with the common diet with 165 g/kg crude protein or with a low-protein diet with 140 g/kg of protein, but with added methionine and lysine. The N excretion was strongly reduced (by 25%). Clearly, diets that meet strictly the amino acids requirements of the bird result in less nitrogen excretion. However, poultry is probably more sensitive to a reduction in N in the feed than pigs and therefore, special care is needed when using low-protein feeding to reduce excretion. To reduce N in poultry feeds seems more complicated than to reduce N in pig feeds, probably because our knowledge on the ranking of limiting amino acids is more limited. The order of the limiting amino acids and the economics of use of synthetic industrial amino acids are key issues to reduce the N excretion by poultry.

The IPPC Reference Document on Best Available techniques for the intensive rearing of poultry and pigs (IPPC, 2003) provides also recommendations for low-protein feeding of poultry. The suggested indicative crude protein values as best available technique (BAT) have been summarized in Table 12. The highest protein content is for young turkeys (27 - 22 %) and young broilers (22-20%) but these animals also have the highest N retention (about 45-50%), because of their fast growing rate. Laying hens and 'old' turkeys have a relatively low protein requirement (17 to 14 % protein, equivalent to 27 to 22 g N per kg).

Table 12. Suggested indicative crude protein values for poultry, as best available technique (BAT), according to the IPPC Reference Document on Best Available techniques for the intensive rearing of poultry and pigs (IPPC, 2003).

Species	Phases	Crude protein content (% in feed)	Remark
Broiler	starter	20 – 22	With adequately balanced and optimal digestible amino acid supply
	grower	19 – 21	
	finisher	18 – 20	
Turkey	<4 weeks	24 – 27	
	5 – 8 weeks	22 – 24	
	9 – 12 weeks	19 – 21	
	13+ weeks	16 – 19	
	16+ weeks	14 – 17	
Layer	18 – 40 weeks	15.5 – 16.5	
	40+ weeks	14.5 – 15.5	

Table 5.5: Indicative crude protein levels in BAT-feeds for poultry

Comparison of the results reviewed by Matteos et al (2005) with the indicative crude protein values according to the IPPC Reference Document on Best Available techniques for the intensive rearing of poultry and pigs (IPPC, 2003), suggest that there is still some scope for further decreasing the protein level of poultry feed. This is also the notion of experts of the European Animal Feed Association and of the Animal Sciences Group of Wageningen University. Based on the results of Matteos et al (2005) and other experts, it is reasonable to suggest that the protein content of poultry feeds, including the suggested indicative crude protein contents according to the BREF of the IPPC (2003) may be lowered by 5-10% during the next 10 to 15 years. However, this requires further research about the critical amino acids in the various diets, and training and support of farmers, as well as the provision of animal feed with the proper amino acids in balance.

It should also be noted that poultry in battery cages has lower (10-20%) N excretion than poultry in ground-based housing systems. The current trend in some countries is from battery cages to ground-based systems, because of animal welfare regulations.

Summarizing, the mean N excretion of poultry may decrease perhaps by 5-10% through a lower protein content of the animal feed and a more adjusted (phase-) feeding, over a 15 to 20 year time period (2020/2025 as horizon). This modest decrease follows from the current rather low mean N excretion values, and from the trend towards ground-based housing systems.

3.9. Discussion

The previous analysis suggests that there is scope for lowering the total N excretion of animals in the EU-25+ by roughly 10% through a combination of measures, including:

- lowering the protein content of animal feed, with or without additions of specific amino acids and improved phase feeding;
- improvement of the genetic potential of the herds, i.e., increasing the milk yield per cow and the growth rate of pigs, poultry and beef animals;
- lowering the replacement rate of dairy cattle, increasing the growth rate of young dairy stock and lowering the age of the young stock at first calving;

There are additional high-technological measures, such as the use of antibiotics, antimicrobial agents, and certain growth hormones, but these measures are not considered here, because of animal welfare reason.

Note also that the analysis has been restricted to the main livestock categories dairy cattle, other cattle, pigs and poultry. It is reasonable to suggest that the scope and effects of lowering the N excretion of other animals (mainly sheep and goat) is limited, because these animals are kept mainly on extensively managed pastures and farms

Also a top-down enforced decrease of the number of animals is not included in this analysis, although it will be clear that decreasing the number of animals (via implementation of for example a quota system) could be very effective in decreasing the N excretions and also the N emissions resulting from the N excretions. However, an enforced decrease of the number of animals is not included in this analysis

The available data do not allow to making a more precise estimate of the potential for decreasing the N excretion by animals in the EU-25+, than the suggested rough mean of 10%. The accuracy of the estimated potential decrease in N excretion is on the one hand constrained by our limited knowledge of the animal physiology and especially the animal nutrition (the minimum requirement for amino acids), and on the other hand by our limited knowledge of current practice. The current information in the RAINS database indicates that (i) there is little variation in practice as regards the N excretion of dairy cattle, other cattle, pigs and poultry among countries, and (ii) that the N excretion of these main livestock categories in the various countries is not (excessively) high. Hence, on the basis of the RAINS database, there is only limited scope for decreasing N excretion. The data also indicate that there is very limited scope for regional differentiation in the scope for decreasing N excretion. But it is unclear to which extent the information in the RAINS database indeed reflects the variations in current practice.

It is recommended that a thorough survey is being made of the animal feeding practices in the EU-25+, and that a uniform methodology is applied for estimating the regional variation in N excretion by animals. The current N excretion values in RAINS are based on estimates by country specialists, and it is unclear whether these estimates reflect indeed the variation that occurs in practice. This holds as well for the projected number of animals for the next decades. More precise estimates of the regional variation in N excretion will also allow to making more accurate estimates of the potential for decreasing N excretion by animals.

The suggested decrease of the N excretion by animals by roughly 10% in the next 10 to 15 years will be achieved only with proper incentives, including

- training and advising farmers;
- demonstration trials and farms;
- covenants with animal feed industry and farmers;
- research for improving the requirement of animals for amino acids and the diagnosis of amino acids in diets.

The prospects of decreasing the N excretions of animals will depend on the current situation of animal feeding in practice, the education and management level of farmers, the animal physiological limits of animals, and the economic and social costs of doing so (Van Bruchem et al., 1999; Oltenacu et al., 2005; Oenema and Tamminga, 2006). It will vary per country and per animal category, but there is very limited knowledge at this stage for making precise estimations of regional differentiated predictions.

4. Improving N use efficiency through balanced N fertilizer application

4.1. Introduction

On average, less than 50 of the applied N to crops via fertilizer and animal manure is taken up by the crop (e.g., Mosier et al., 2004). The other 50 is, for a greater part, dissipated in the wider environment, causing various environmental and ecological side effects. These N losses are also an economic loss to farmers, especially when fertilizer costs represent a large fraction of the total costs of farming. It is commonly accepted that significant improvements must and can be made in N use efficiency (NUE) to produce enough food for feeding the growing human and animal populations and to avoid large-scale degradation of ecosystems caused by excess N.

Nitrogen Use Efficiency (NUE) is a commonly used indicator in agriculture, but its value highly depends on the way it defined and calculated. In field studies, four agronomic indices are commonly used to measure NUE: partial factor productivity (PFP_N), agronomic efficiency (AE_N), apparent recovery efficiency (RE_N), and physiological efficiency (PE_N) as defined in Mosier et al., 2004). Here, we use NUE in a general terms, to express the use efficiency of N sources, and thereby can be considered as 'apparent recovery efficiency' of applied N fertilizer, animal manure and crop residues.

The key factors that control the N use efficiency (NUE) at crop level in agriculture are: (i) crop N demand, (ii) N supply, and (iii) N losses. Each of these factors is influenced by several processes and variables, as shown in Figure 7. Some processes can be managed in a field (e.g., delivery of nutrients, disease control), but other variables cannot be controlled (temperature, rainfall or soil texture).

The processes and variables that control the uptake of N by crops (and thus the NUE as the control center in Figure 7) can exert a direct or an indirect effect on RE_N, and they can also be placed in an order of increasing significance. Hence, the processes and variables, which have a direct effect on NUE and placed at a high level of significance, will exert a major control on NUE. In contrast, processes and variables operating at an indirect level and placed at a low level of significance will have less effect on NUE.

Foremost, the NUE by a crop is driven by its demand for N. Crop yield is highly correlated with total N uptake. Crop N demand is directly related to certain fundamental processes, associated with crop growth, i.e., light (energy) and temperature. Availability of water and other nutrients (P, K, Mg, S) increases crop demand for N and NUE.. The NUE will further increase when insect pests, diseases and weeds are eliminated.

N supply in the soil originates from application of N via manure and fertilizer or from net mineralization of SOM or crop residues, and atmospheric deposition. The NUE is partly dependent on how much mineral N originated from current N application versus net mineralization of SOM or unused N from previous applications (Figure 7). Of more significance in controlling NUE, however, is the synchronization of N supply with crop demand for N. For example, split N application could synchronize N supply with the crop demand for N, leading to higher NUE.

By creating a strong sink for applied N in the crop, i.e., removing all growth limiting factors, and by providing an optimum delivery system of N to the crop, a maximum NUE value of 90 (assuming 10 of the acquired N remain in the roots) could be theoretically obtained. However, the theoretical maximum NUE value is never obtained because it is impossible to optimize all factors that control crop N demand, N supply and N losses. Applied N can be lost via denitrification, leaching, runoff, volatilization, and/or soil erosion (Figure 7).

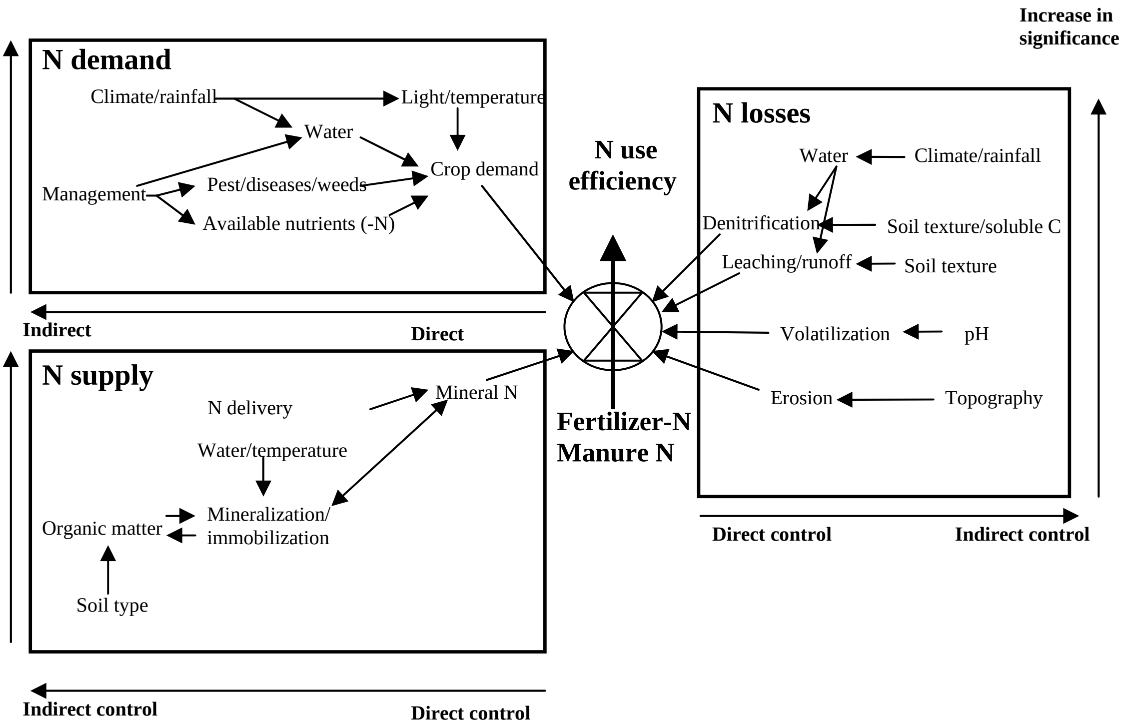

Figure 7. Conceptual model depicting the three main control boxes (i.e., N demand, N supply and N losses) and their major processes and variables, regulating N use efficiency (NUE). The symbol in the center of the figure represents the 'control center', which influences the flow of applied N into the crop and therefore the NUE. The horizontal listing and their distance from the 'control center' of the processes and variables within each box reflect their direct or indirect effect on NUE. The vertical location of processes and variables within each box reflects their level of significance on NUE (after Mosier et al., 2004).

In practical terms, improving NUE requires a coherent package of measures. One of the most important measures is improving the overall management of the soil and the crop, and 'matching N supply to N demand', i.e., prevent 'overfertilization'. In addition, various additional measures can be taken, as indicated also in the Code of Good Agricultural Practices of the Nitrate Directive. These include proper techniques and timing for the application of fertilizers and animal manure so as to circumvent N losses via ammonia volatilization and leaching losses, and no application of manure and fertilizers in autumn and winter and on wet and sloping soils.

The concept of "balanced fertilization" as implemented in MITERRA is detailed further below. It estimates the degree of overfertilization in practice in the EU-25 for the year 2000 and hence the scope for lowering N input and improving N use efficiency. The evidence for overfertilization is scattered however. Results of the CAPRI database suggest for some countries a considerable N surplus, suggesting that there is scope for a decrease. This holds much less for the new member states of the EU, which have faced a considerable drop in the use of fertilizers.

4.2. Current level of fertilization in EU-25+

Estimating the adequacy of N fertilization (i.e., the degree of overfertilization) at the level EU-25+ or at member state and regional levels is not an easy task. The fertilization depends on a whole complex of socio-economic, cultural and environmental (natural conditions) factors. Key indicators for assessing the adequacy of N fertilization at regional and national levels are (see also Figure 7):

- crop type and crop yields;
- inputs of N via fertilizer and animal manure; and
- surpluses of N.

When using N surpluses as indicator, a proper distinction must be made between crop production farms and animal production farms. Crop production farms have much lower N surpluses, because these farms include only one trophic level. Mixed animal farms include two (crops and animals) trophic levels and thereby have much greater opportunities for N to escape from the system and much lower N retention. In crop production systems, the N surplus will depend on (i) natural factors and conditions (climate, soil type, geomorphology) and (ii) management related factors (type of crop, use and management of animal manure and fertilizers, irrigation, etc.). The combination of these factors defines the actual N surplus. In this paragraph, we briefly summarize the inputs of N fertilizer and animal manure and the surpluses of N, so as to assess the adequacy of N fertilization and the scope for improving the N use efficiency in crop production. The focus is on N inputs via N fertilizer and animal manure and on N surpluses.

The total N fertilizer input in the EU-25+ has started to decrease from the end of the 1980s, following a steady increase from the 1950s onwards (Figure 8). The sudden drop in the early 1990s is caused by the political changes in the new member states from central Europe. The current level of N fertilizer use in these central European countries is still rather low, for Economical reasons, probably below optimum. Hence, the current trend in N fertilizer for the whole EU-25+ are the resultant of a steady decrease in N fertilizer use in the EU-15 member states and a variable but slight increase in the new member states in Central Europe. The total N input via N fertilizer in EU-25+ is about 10 Tg per year (Figure 8).

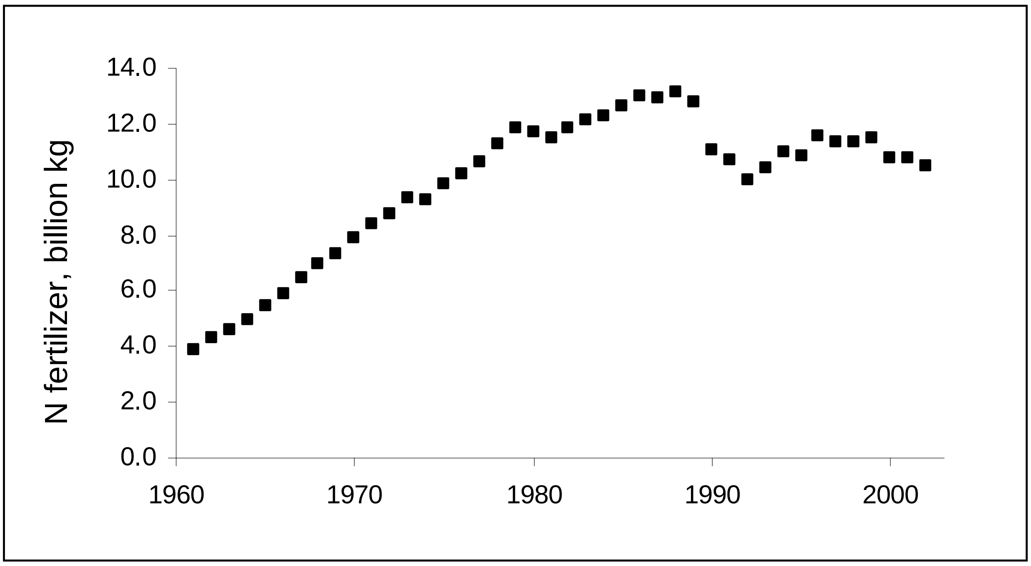

Figure 8. Trend in N fertilizer use in EU-25+, based on FAO data.

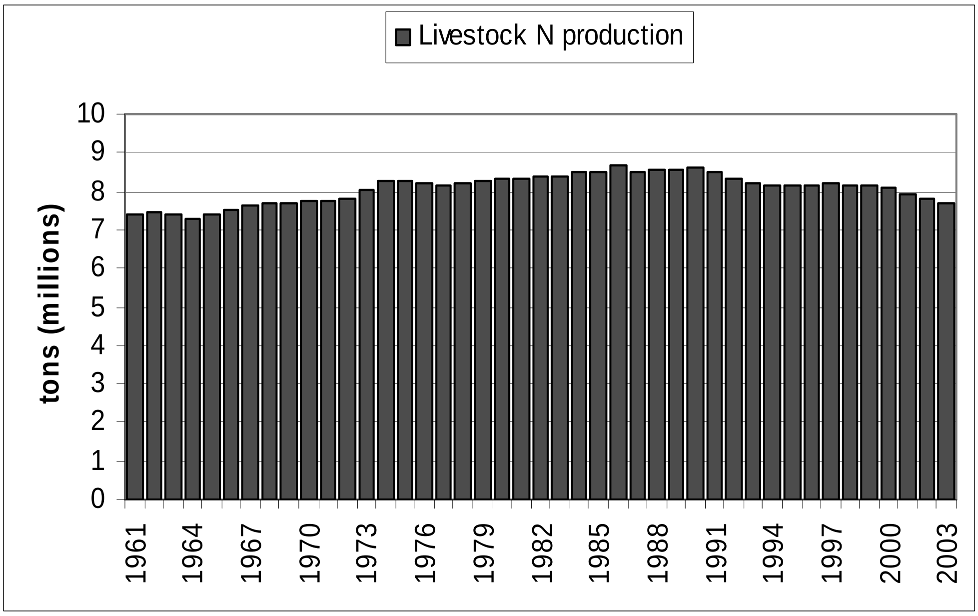

Figure 9. Trend in the mean production of N in animal manure in EU-25+ (after Zwart et al., 2006).

The amount of N in livestock manure is slightly decreasing from the end of the 1980s onwards (Figure 9), and is currently only slightly less than the amount of N fertilizer in the EU-25+. The slight decrease in the amount of N is the resultant of the decrease of the number of dairy cattle in the EU (due to the milk quotum), the decrease in the number of cattle, pigs and poultry in the new member states from central Europe following the political changes in the early 1990s, and the increases in the number of pigs and poultry in EU-15 and the increase in N excretion per dairy cow (because of the increase in milk yield per cow).

The area of agricultural land in the EU-25+ has also steadily decreased from the second half of the 1980s onwards, especially in the new member states of Central Europe (land abandonment), and due to the increasing areas used for urbanizations and nature conservation. Current areas of major agricultural crops are presented in Table 13.

Table 13. Areas of main agricultural crops in the EU-25+ in the year 2000, according to CAPRI database. For definition of crop groups, see Velthof et al. (2007).

	Areas of major crop groups, in 1000 ha.				
Country	Root crops (C1)	Cereals (C2)	Fruits (C3)	Forage crops (C4)	Total
AT	623	356	139	1062	2180
BL	443	65	68	768	1345
CZ	1844	264	162	1217	3488
CY	67	6	36	23	133
DE	6782	1958	475	5835	15049
DK	1533	126	42	860	2562
EE	264	70	8	348	689
ES	5076	2913	5581	5742	19311
FI	867	476	30	243	1616
FR	8084	3282	1783	12741	25890
EL	435	1074	2031	1233	4772
HU	1885	1899	317	1378	5479
IR	341	21	5	3454	3820
IT	1664	3395	3028	5000	13087
LT	904	229	88	1176	2396
LU	28	3	12	80	122
LV	400	133	20	760	1313
MT	4	0	2	5	11
NL	569	42	82	1196	1889
PL	5373	4930	582	3526	14412
PT	145	470	794	1227	2637
SE	979	370	42	1128	2518
SI	66	53	33	187	339
SK	812	308	60	750	1930
UK	3783	145	335	10358	14620
BG	1653	967	367	1394	4382
RO	3412	4228	678	4655	12973

Surpluses of N for the EU-15 are presented in Table 14 and for the new member states at NUTS-2 level in Figure 10. Mean N surpluses differ between Member states by a factor of 10 in the year 2000, ranging from 24 kg per ha per in Portugal to 256 kg per ha in the Netherlands. Table 14 clearly shows that the main inputs are via N fertilizer and animal manure. There is a strong correlation between the N output via harvested crop (crop N removal) and the N input via fertilizer, animal manure and also atmospheric deposition. The strong correlation between crop N removal and amounts of animal manure follows from the fact that forage crop fed to cattle have a high N uptake. Hence, proper assessments of the adequacy of N fertilization on the basis of N input and N output data as presented in Table 14 can only be made when additional information about the farming systems and crop systems are taken into account.

Table 14. Average input of N (via N fertilizer, biological N fixation, and atmospheric deposition), average N output (via harvested crop, including grazed grass), and average N surplus, in kg per ha in the year 2000, according to Eurostat.

Country	Mineral N fertilizer	Biological N fixation	Organic manure	Atmospheric deposition	Crop N removal	N surplus
United Kingdom	77	3	67	15	125	37
Netherlands	184	1	265	36	230	256
Austria	33	3	48	20	68	36
Belgium+Luxemb.	114	3	220	33	225	145
France	89	5	46	16	116	40
Ireland	91	1	123	10	162	63
Italy	62	2	45	12	80	41
Denmark	106	8	114	18	135	111
Germany	104	3	65	29	109	92
Spain	41	3	23	6	38	35
Greece	88	2	49	7	98	48
Finland	81	3	39	5	72	56
Portugal	31	2	39	3	51	24
Sweden	66	4	39	5	79	35

The N surpluses in the new member states are on average lower that those of the EU-15, except for Malta (MT), Cyprus (CY) and Slovenia (Sl). Average N surpluses of most new Member States is in the range of 25-50 kg N per ha per year (Figure 10), and with little regional variation. Surpluses in new member states in Central Europe have dropped significantly in the 1990s following the drop in N fertilizer use (see Figure 8). The current low N surpluses in the new member states in Central Europe suggest little wasting of N and also little scope for lowering N input. However, crop yields are also low. For the next few decades, it is reasonably to assume that crop yields and N input will go up again. There are considerable differences in mean N surpluses at national level between the estimates provided EUROSTAT, OECD and CAPRI (Velthof et al., 2007), suggesting uncertainties and errors in the statistical information. Hence, the N surpluses must be considered with caution.

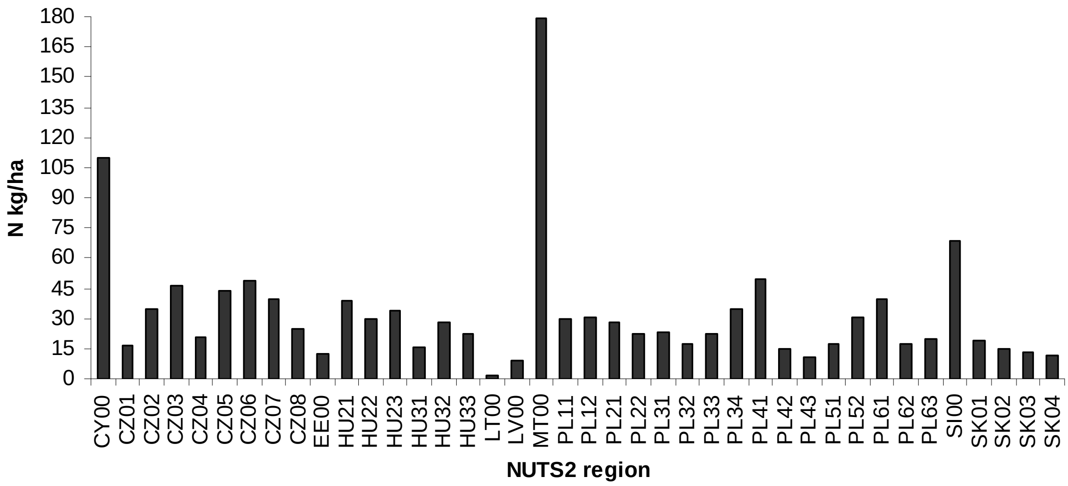

Figure 10. Mean N surplus at regional level in the new member states in 2000, according to the CAPRI database.

4.3. Matching N supply to N demand

Matching N supply to N demand of the crop means that the amount of applied plant available N via fertilizer and animal manure is tuned to the crop N demand, while due accounts are made of N inputs via atmospheric deposition, mineralization of soil organic matter and crop residues, and biological N fixation. In practical modeling terms, this requires the following assessments:

I. Assessment of the N demand of the crop:

In MITERRA-EUROPE, the crop yield and the amount of N removed via harvested product in the year 2000 are used for the assessment of N demand per region (Velthof at al. 2007). Apart from grassland, crop yield data for 2000 have been derived from FAO. Grassland yields were estimated on the basis of various data sources (Velthof et al., 2007). Crop yields for all crops in EU-15 Member states were assumed to stay constant between 2000 and 2020, while crops yields of all crops in the new Member States were assumed to increase by on average 15% (following the drop in the 1990s). The non-harvested crop parts (roots and crop residues) are estimated for each crop (using crop types of CAPRI). Data on the ratio between N in harvested products and N in crop residues are based on Velthof & Kuikman (2002)

II. Assessment of the total amount of plant-available N

In MITERRA-EUROPE, sources of plant-available N are:

- Manure (= excretion in stable, corrected for gaseous losses in stable):
- Excretion during grazing (= excretion during grazing, corrected for gaseous N losses).
- Fertilizer (= fertilizer applied, corrected for gaseous N losses).
- Biological N fixation
- Atmospheric N deposition
- Crop residues
- Mineralization of N from soil organic matter

To estimate the amount of plant-available N a fertilizer N equivalency is introduced in MITERRA-EUROPE. The fertilizer equivalency is defined as the fraction of N of a particular N source that is available to crop uptake. The availability of N fertilizer containing only nitrate, applied under conditions without surface runoff is by definition set at 100%. The most common N fertilizers containing nitrate and/or ammonium have a fertilizer equivalency < 100, because some ammonia volatilization occurs. Table 15 provides on overview of the fertilizer equivalency (fq_{fert}) used in MITERRA-EUROPE.

Accounts are made for the mineralization of N from manure and crop residues during the year of application. The residual organic N in crop residues and animal manure after 1 year is attributed to the soil organic matter pool (hence will contribute to the mineralisation of N from soil organic matter).

The total amount of plant-available N is calculated as follows:

fertilizer * fq_{fert} + manure N * fq_{man} + excretion during grazing * fq_{ex} +
biological N deposition * fq_{biol} + atmospheric N deposition * fq_{atm} + mineralization * fq_{nmin}

Mineralization of N from soil organic matter is a very sensitive parameter, and various sensitivity analyses were carried out. In most scenarios, the organic N content of agricultural soils was considered to be constant (hence, no net N mineralization).

Not all crops have the ability to take up all ‘available N” from the soil. In this case, we distinguished three categories of crops. Grassland is considered to be highly effective in taking up ‘available N’ from the soil (permanent cover all year round, extensive rooting system) and the ‘efficiency factor was set at 1.0. Cereals are considered to be also effective in taking up ‘available N’ from the soil (relatively long growing season, extensive rooting system) and the ‘efficiency factor was set at 1.1, while all the efficiency factor for all other crops was set at 1.25, indicating that the supply of plant available N has to be 1.25 times the N demand of the crop. Evidently, the choice of the efficiency factor is a highly critical factor.

III. Matching N demand to N supply

In a perfect match, the total supply of plant-available N is equal to the total N demand of the crop. If the amount of plant-available N is smaller than the N demand of the crop, the crop yield is less than optimal. If the amount of plant-available N is larger than the N demand of the crop, the crop yield is assumed to be optimal, but N losses to the environment are larger than in the case of a perfect match. Hence, with 'balance fertilization' N supply is equal to N demand of the crop.

Table 15. Fertilizer equivalency values (fq_{fert}) of N sources, as used in MITERRA-Europe (after Velthof et al., 2007).

N source	**Fertilizer N equivalency**	**Assumptions**
Fertilizer: fq_{fert}	100 – NH_3-loss from fertilizer – surface runoff fertilizer, %	
Manure inorganic N: fq_{man}	100 – NH_3-loss from manure – surface runoff manure, %	Assumption: liquid manures contain 60% mineral N, solid manures contain of 25% and excretions during grazing 50%.
Grazing: inorganic : fq_{ex}	80 - NH_3-loss from grazing – surface runoff grazing, %	Assumption that N concentration in urine patches exceed locally the N uptake capacity of the grass, by which a part (20%) is not plant-available, i.e. in winter.
Biological N deposition: fq_{biol}	100% of total fixed N	
Atmospheric N deposition: fq_{atm}	75 % of total deposited N	Assumption that on average 25% of the N is deposited in period with no crop uptake, i.e. in winter
Gross mineralization of soil organic N in mineral soils: fq_{min}	For grassland: 90% from the gross mineralization of organic N in mineral soils. For arable land: 70% from the gross mineralization of organic N in mineral soils. Gross mineralization = N in crop residue in 2000 + organic N in manure + organic N excreted during grazing	Assumption: the gross mineralization is equal to the organic N added via crop residues, manure and grazing in a steady state situation (no change in organic N content of the soil). The amount of crop residue is fixed at the amount in 2000 to facilitate calculation of yield in dependency of the amount of plant-available N. It is assumed that on average 25% of the N is mineralized in period with no crop uptake.

If the amount of plant-available N is higher than the crop demand (i.e. overfertilization), the N input may be decreased. The first step to achieve a perfect match of supply of plant-available N to the total N demand of the crop ('balanced fertilization') is to decrease the N fertilizer input. When 'balanced N fertilization' can not be achieved by deleting N fertilizer application, also the application rate of animal manure N has to be decreased. The surplus manure has to be exported to other regions or to be treated and removed from agriculture. Here, we distinguished two categories of crops; (i) grassland, where there is no minimum N fertilizer and all N fertilizer may be withheld, and (ii) all other crops where the minimum N fertilizer dressing is 50% of the dressing in 2000.

Balanced fertilization may result in an increase of the fertilization equivalence factors for fertilizers and animals (as indicated in Table 15). This is as yet not explicitly programmed in MITERRA-EUROPE yet.

The total amount of N applied via animal manure does not exceed 170 kg per ha per year, unless the area has been granted a derogation of this obligation of the Nitrate Directive, and is allowed to apply more. This holds for some farms in Austria, Germany, Denmark, Netherlands, Belgium, and Ireland. The procedures for estimating the amount of N from animal manure per NUTS 2 area with farms that have derogation are described in detail in Velthof et al., 2007).

Summarizing:

1) The total N demand of the crop is calculated, on the basis of statistical (Eurostat, FAO, CAPRI) data and literature data for N uptake by the crop;
2) The total amount of plant-available N is calculated, again on the basis of statistical (Eurostat, FAO, CAPRI) data;
3) The overfertilization factor per crop and NUTS-2 level is derived, on the basis of the total amount of plant-available N > total N demand of the crop.
4) Balanced fertilization is approached by decreasing N fertilizer input to the level of the N demand by the crop. If balanced N fertilization is still not achieved after a decrease of fertilizer application (till 50% of the original N application for all crops except grassland), the application rate of manure N is reduced. The excess manure is assumed to treated and removed from agriculture.
5) The environmental effects of balanced fertilization are assessed, using MITERRA, relative to the Reference run.

4.4. Discussion

The previous analysis (indirectly) suggests that there is scope for improving the N use efficiency in crop production by more efficient use of animal manure and fertilizers and hence by a lower fertilizer N input. This holds especially for the intensively managed crop production systems (including forage production) in many of the EU-15 Member States.

There are various reports from Member States indicating that significant improvements have been made in N use efficiency and in decreasing N surpluses in agriculture through a combination of measures. Denmark is a typical example in this case. Figure 11 shows that the N use efficiency in Danish agriculture has increased steadily during the last 10 to 20 years, and that N surpluses have dropped steadily. The success of the Danish case has been ascribed to two factors, namely (i) mandatory fertilizer and crop rotation plans, with limits on the amount of plant available N to be applied to different crops, and (ii) the statutory norms for the fraction of manure N assumed to be plant available (the fertilizer equivalence factors fq_{man} for manure in Table 15). These two instruments have been enforced (and became more strict) in several rounds between 1991 and 2004. These regulations have been designed in close dialogue with farmers and farmers associations and have been followed up by information materials, demonstration, extension and education. Also, extensive research programs have been supported (Dalgaard, 2006). Rather similar success stories have been reported for the Netherlands (Van Grinsven et al., 2005).

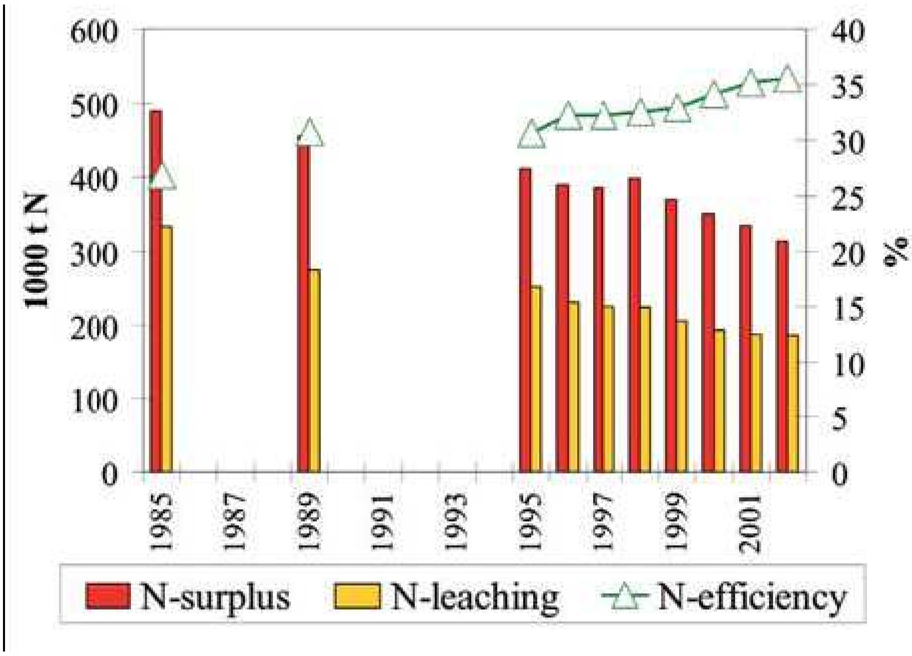

Figure 11. Changes in the N surpluses, N leaching and use efficiency of N in Danish agriculture (after Dalgaard et al., 2006).

The lessons to be learned from the Danish case and other cases is that a steady lowering of N surpluses and a steady increase of the N use efficiencies can be made only following the implementation of sound policies and measures, including the training of farmers and extension services, and supported by extensive research programs. Mosier et al (2004) state that improvements in NUE require knowledge intensive N management practices and are brought about by:

- increased yields and more vigorous crop growth, associated with greater stress tolerance of modern crop varieties
- improved management of production factors other than N (tillage, seed quality, plant density, weed and pest control, balanced fertilization of other nutrients than N (see also Figure 7), and
- improved N fertilizer and animal manure management, to better match the amount and timing of applied N to crop N demand.

Prerequisites for implementing such practices are that they must be simple and user friendly, involve little extra time, provide consistent gains in NUE and crop yield and are cost-effective. Optimizing the timing, quantity and availability of applied N is the key to achieving a high NUE.

Further increases in NUE of about 10-30 relative to present levels appear feasible in many regions, through fine-tuning of the N management (Mosier et al, 2004). They require suitable policies and significant long-term investments in research, extension and education. The policies and investments need to be regional specific, because of the different agricultural practices and priorities in different countries.

In practical modeling terms, in MITERRA-EUROPE, improving NUE is brought about by a combination of:

- lowering N fertilizer input, without change in crop N removal;
- increasing the fertilizer equivalence factor for manure (fq_{man}), combined with a lowering of the N fertilizer input, but without a change in crop N removal;
- increasing the fertilizer equivalence factor for fertilizer and other N sources (fq_{fer}; f_{crop}), and thereby increasing crop N removal, without changing N fertilizer input

5. Optimal combination of NH_3 emission abatement and balanced fertilization

5.1. Introduction

In EU-27, about 75% of the NH_3 emitted to the atmosphere can be attributed to livestock production (Webb et al., 2005; Amann et al., 2006b), and hence, measures restricting NH_3 emissions from the livestock sector are considered to be the most effective approach to reduce the impact of NH_3 on the environment. On average more than one-third of the total amount of N excreted by animals in dung and urine in the EU-27 is emitted into the atmosphere. The fraction emitted greatly depends on whether the animals are grazing or housed indoor, and on the animal housing systems, the manure storage systems, and the application of animal manure to land. The fractions emitted can be greatly lowered through technological and management measures, and various Member States have implemented various measures already in practice. Because of the large fraction of the excreted N that can be lost and the availability of various effective measures, NH_3 emission abatement measures fall in the category 'most promising measures, as defined in the call for tender (see also chapter 1). However, some of these measures are costly and have the risk of increasing other emissions, when not integrated properly. Hence, the challenge is to find the most cost-effective set of measures and to integrate the measures with integrated N management (balanced N fertilization).

5.2. Overview of NH_3 emission abatement measures

Guidelines for ammonia abatement have been developed and are being updated by Working Group on Ammonia Abatement of the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP). In a guidance document (Framework Advisory Code of Good Agricultural Practice to reduce Ammonia Emissions, to be found at:
http://www.unece.org/env/documents/2001/eb/wg5/eb.air.wg.5.2001.7.e.pdf),
an overview is presented of the best available techniques to reduce ammonia emissions from all major on-farm sources (animal house, storage, spreading manure), and for all animal categories (including cattle). Besides emission reduction potential compared to traditional systems (e.g. uncovered storages), also economic data (investments, costs) are provided. The guidance document is updated on a regular basis, under supervision of the CLTRAP Expert Group on Ammonia Abatement (established under the Working Group on Strategies and Review). The Code of Good Agricultural Practice to reduce Ammonia Emissions of the UNECE- CLRTAP comprises six sections, as follows:

1. Nitrogen management that takes into account the entire N cycle;
2. Livestock feeding strategies;
3. Low-emission manure spreading techniques;
4. Low-emission manure storage techniques;
5. Low-emission animal housing techniques;
6. Limiting ammonia emissions from the use of mineral N fertilizer

The Code includes guidance on reducing ammonia emissions from all the major agricultural sources for which practical and widely applicable techniques are available. Detailed guidelines have been made for livestock feeding strategies, low-emission manure spreading techniques, low-emission manure storage techniques, low-emission animal housing techniques, and the use of mineral N fertilizer that limit ammonia emissions. The guidelines for "Nitrogen management that takes into account the entire N cycle" (Section nr 1) are very similar to the Code of Good Agricultural Practice of the Nitrates Directive. The ammonia abatement options presented in the BREF under the IPPC Directive and in the Framework Advisory Code under UNECE-CLTRAP are very similar, except for cattle which is not included in the IPPC.

Examples of the ammonia abatement options for cattle houses, and manure storage are presented below in Tables 16, 17 and 18.

Table 16. Overview of ammonia abatement measures in the CLTRAP Framework Advisory Code of Good Agricultural Practice to reduce Ammonia Emissions from cattle housing stables.

Housing type	**Reduction (%)**	**Ammonia emission (kg/cowplace.year)**
Cubicle house	-	11
Tying stall	60	4.4
Grooved floor	25	8.3
Solid manure, sloped floor or deep litter system	30	7.5
Flushing and scraping systems	25	No practical data

Table 17. Ammonia abatement efficiencies of manure application techniques (UNECE, 1999).

Method	**Abatement efficiency, %**
Trailing hose	30
Trailing show	40
Injection, open slot	60
Injection, closed slot	80
Incorporation of surface applied manure directly into the soil	80

Table 18. Overview of ammonia abatement measures for manure storage in the CLTRAP Framework Advisory Code of Good Agricultural Practice to reduce Ammonia Emissions.

Abatement measure	Livestock class	Ammonia reduction, %	Applicability	Costs, €/m3.yr
Lid, tent, roof	all	80	Concrete or steel tanks and silos	8
Plastic sheet or floating cover	all	60	Small earth banked lagoons	1.25
Plastic sheet or floating cover	all	60	Large earth banked lagoons	1.25
Low tech floating cover (peat, chopped straw, LCA…)	all	40	Concrete or steel tanks and silos	1.10
Natural crust on tank or lagoon	Cattle	35-50	Not when mixing is required upon spreading	0
Replacement of lagoons with tanks	All	?		14.9 (cost of tank: 6.94)
Storage bag	All	100	Bag sizes may be limited for use on larger farms	2.5

5.3. NH_3 emission abatement measures in RAINS/GAINS

The major ammonia emissions abatement categories for agriculture considered in RAINS/GAINS are similar to those of the Code of Good Agricultural Practice to reduce Ammonia Emissions of the UNECE- CLRTAP. The major abatement categories for agriculture considered in RAINS/GAINS are:

1. Low N Fodder (dietary changes), e.g., multi-phase feeding for pigs and poultry, use of synthetic amino acids (pigs and poultry), and the replacement of grass and grass silage by maize for dairy cattle;
2. Stable Adaptation by improved design and construction of the floor (applicable for cattle, pigs and poultry), flushing the floor, climate control (for pigs and poultry), or wet and dry manure systems for poultry;
3. Covered Manure Storage (low efficiency options with floating foils or polystyrene, and high efficiency options using tension caps, concrete, corrugated iron or polyester);
4. Biofiltration (air purification), i.e., by treatment of ventilated air, applicable mostly for pigs and poultry, using biological scrubbers to convert the ammonia into nitrate or biological beds where ammonia is absorbed by organic matter;
5. Low Ammonia Application of Manure, distinguishing high efficiency (immediate incorporation, deep and shallow injection of manure) and medium to low efficiency techniques, including slit injection, trailing shoe, slurry dilution, band spreading, sprinkling (spray boom system).
6. Urea substitution, substitution of urea with ammonium nitrate; and
7. Incineration of poultry manure

RAINS/GAINS does include the specific measure “biofiltration” or “air purification’ which decreases NH_3 emissions from livestock houses. It does include the specific measure “incineration of poultry manure”, which can be seen as a variant of Low Ammonia Application of Manure. However, RAINS does not include the measure “Nitrogen management that takes into account the entire N cycle”.

The removal efficiencies for NH_3, N_2O, and CH_4 on a country level for the so-called “RAINS measures” are shown in Tables 19 and 20. This Table shows that some of the measures have effect on one specific NH_3 source (BF, CS, LNA), while other measures have effect on more than one NH_3 emitting source (e.g. LNF, SA).

Table 19. The removal efficiencies for ammonia from RAINS on a country level (table 5.1 in Klimont & Brink, 2004).

Table 5.1: Emission control options for NH_3 considered in the RAINS model and their assumed removal efficiencies (based on the UNECE, 1999b: EB.AIR/WG.5/1999/8 Rev.1)[a].

		Removal efficiency [%]			
Abatement option	**Application areas**	*Animal house*	*Storage*	*Application*	*Grazing*
Low nitrogen feed (LNF)	Dairy cows	15	15	15	20
	Pigs	20	20	20	n.a.
	Laying hens	20	20	20	n.a.
	Other poultry	10	10	10	n.a.
Biofiltration (BF)[b]	Pigs, poultry	80	n.a.	n.a.	n.a.
Animal house adaptation (SA)	Dairy cows	25	80	n.a.	n.a.
	Other cattle	25	80	n.a.	n.a.
	Pigs	40	80	n.a.	n.a.
	Laying hens	65	80	n.a.	n.a.
	Other poultry	85	80	n.a.	n.a.
Covered storage (CS_low/high)	Dairy cows, other cattle, pigs, poultry *[liquid manure]*	n.a.	40/80	n.a.	n.a.
Low NH_3 application (LNA_low/high)	Dairy cows, other cattle, pigs, poultry, sheep *[solid waste]*	n.a.	n.a.	20/80	n.a.
	Dairy cows, other cattle, pigs *[liquid manure]*	n.a.	n.a.	40/80	n.a.
Urea substitution (SUB)	Fertilizer use	80 – 93			
Stripping/adsorption	Industry	95			
Manure incineration	Other poultry	~60 [c]			

[a] For some countries changes to these numbers where made as RAINS allows for country-specific reduction efficiencies, these was based on consultations with national experts during the work on the scenarios for Gothenburg Protocol. [b] Although some countries indicated that this option is also available for cattle (because some animal houses are equipped with mechanical ventilation), it has not been implemented in RAINS, yet. [c] Based on the example for UK, the values might vary from country to country.

n.a.: not applicable

Table 20. The removal efficiencies for nitrous oxide and methane RAINS on a country level (table 5.3 in Klimont & Brink, 2004).

Table 5.3: Impacts of NH_3 control options on emissions of N_2O and CH_4 (percentage changes in emissions).

		Sources of CH_4 [b)]	Sources of N_2O			
					Indirect emissions	
Control options	Livestock category	Manure management	Animal production	Direct soil emissions	*N deposition*	*N leaching*
Low nitrogen feed	dairy cows, pigs, poultry	0	– [a)]	– [a)]	– [a)]	– [a)]
Air purification		0	+ [a)]	0	– [a)]	0
Animal housing adaptations	pigs	–10	900	+ [a)]	– [a)]	+ [a)]
	poultry	–90	900	+ [a)]	– [a)]	+ [a)]
Covered storage of manure	cattle, pigs, poultry	10	–10	+ [a)]	– [a)]	+ [a)]
Low NH_3 application (low/high)	cattle, pigs, poultry, sheep	0	0	60/100	– [a)]	+ [a)]
Urea substitution	fertilizer use	0	0	0	– [a)]	0
Stripping/absorption	industry	0	0	0	– [a)]	0

[a)] The effect is calculated on the basis of changes in the N flow due to changes in excretion rates and N-volatilisation rates; [b)] There are no effects of NH_3 abatement on CH_4 emissions from enteric fermentation.

5.4. Cost-effective measures to achieve the Thematic Strategy on Air Pollution

As discussed before (Chapter 3), low-protein animal feeding is an effective and efficient measure as it decreases both NH_3 emissions, NO_3 leaching and direct and indirect N_2O emissions. This measure can be characterized as a highly integrated measure. The measures ‘stable adaptations’, ‘covered manure storages’, ‘low-emission application techniques’, ‘biofiltration’ and replacing urea fertilizers by (ammonium-nitrated) based fertilizers specifically aim at decreasing the loss of NH_3 from the livestock manure. These measures lead to increasing amounts of N in the manure, and will likely lead to pollution swapping if not combined with integrated N management, with a correction of the total N input into the system for the decreased losses via NH_3 emissions. Hence, these measures are only effective and efficient when the total N input into the system is decreased with an amount equivalent to the amount of NH_3-N trapped. This is the main reason why in this optimal combination ‘most promising measure’ NH_3 emission abatement measures are combined with balanced N fertilization, as a way of integrated N management.

Cost-effective packages of measures per Member States have been derived by Amann et al. (2006). These packages of measures lead to a strong decrease of the NH_3 emissions in EU-27, sufficient to achieve the targets of the Thematic Strategy on Air Pollution for NH_3 emission, at the cost of 1.6 billion euro per year (Amann et al., 2006). These packages of measures will lead to pollution swapping, if not combined with integrated N management (see Oenema and Velthof, 2007). Therefore, the package of cost-effective NH_3 emission abatement measures as derived by RAINS/GAINS should be combined with balanced N fertilization as defined by Velthof et al., 2007 and as further explained in Chapters 4 and 6 of this report.

6. Description of the scenarios

Scenarios are narratives of alternative future environments and/or development paths. Scenarios are like hypotheses of different futures, specifically designed to highlight the risks and opportunities involved in specific developments. Scenarios are not predictions; instead, scenarios are an approach to help manage the inherent uncertainties by examining several alternatives of how the future might unfold, and compare the potential consequences of different future contexts (Shearer, 2005).

The most promising measures discussed above have been assessed though 'scenario analyses'. It has been assumed that the most promising measures are implemented in practice by 2020, and the effects of the implementation of the most promising measures have been analyzed in terms of emission decrease, investments and income foregone. This paragraph explains 'the translation of the most promising measures in scenarios'.

The ND full 2020 scenario was used as reference scenario for the analyses of the most promising measures. This scenario has been described in Velthof et al. (2007). The ND full 2020 scenario is based on the "National Projections" baseline scenario for the revision of the NEC Directive (as described in Amann et al., 2006b), but in addition includes a strict interpretation of balanced N fertilization in NVZs. This baseline was chose as reference at the suggestion of the European Commission.

6.1. Description of the low-protein animal feeding scenarios

As regards low-protein animal feeding, there is empirical and theoretical evidence in the literature that the protein content of the animal feed can be lowered, at least on some animal farms, but there is no consensus about the degree of lowering. Two lines of reasoning have been applied in this study to arrive at an estimate of the windows or opportunity for decreasing the N excretion by livestock in EU-27. The first line of reasoning is based on the current N excretion levels in the RAINS database and the theoretical/practical limits based on animal physiology as indicated in literature (see Chapter 3). Taking the mean N excretion values per animal type of the RAINS database as point of departure is based on the fact that RAINS is used as instruments for assessing current and future gaseous N emissions in EU-27. The N excretion values in the RAINS database are based on country specific information provided by experts and are regularly updated. As discussed in Chapter 3 of this report, the gap between the apparent mean N excretion per animal type of the RAINS database and the current theoretical/practical limits is rather (surprisingly) small. This suggest that the scope of lowering the protein content of the animal feed in current practice is relatively small, on average about 10%.

The second line of reasoning is based on statistical/empirical data from practice. For example, data presented in Figure 12 indicates that the N excretion of fattening pigs on specialized farms in the Netherlands ranged from ~10 to ~15 kg per pig place per year, and that the P excretion (expressed as P_2O_5 excretion) ranged from 3 to 6 kg per year in 1999-2000. The scatter suggests that there may be some errors involved in the recording of the data, but the variation also indicates that there is scope for (further) lowering of the

N and P excretion of fattening pigs on many farms by 10 – 30 % (Hubeek and de Hoop 2004).

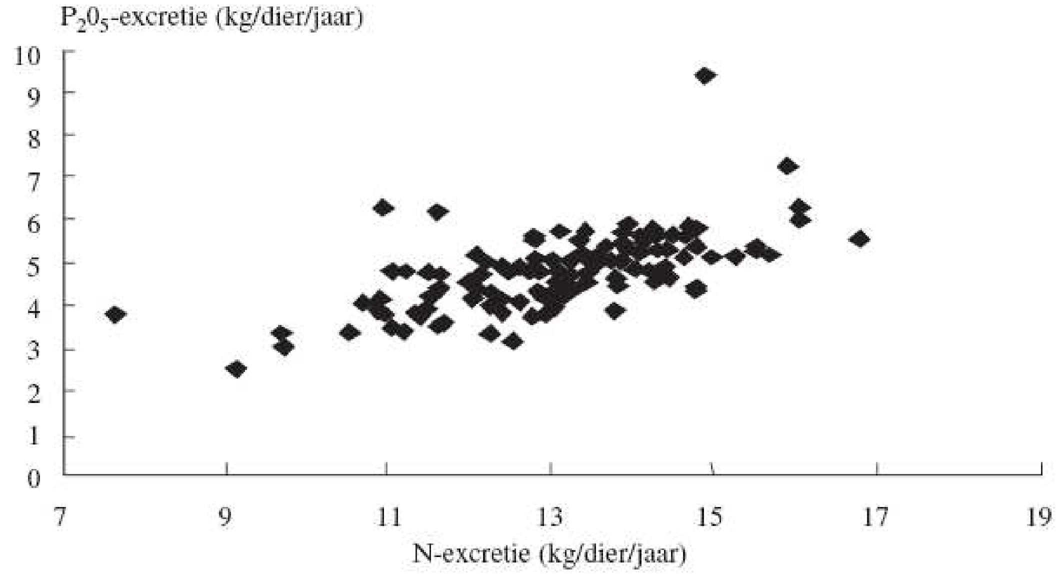

Figure 12. Relationship between the mean excretion of N and P (in P_2O_5) by fattening pigs at farm level in 1999-2000, for specialized fattening pig farms in The Netherlands. ***(****Source FADN database, Hubeek and de Hoop, 2004).*

A similar variation between Member States in mean N excretion of cattle, pigs and poultry has been observed on the basis of data statistics of the animal feed imports, domestic forage and fodder production, and the number of animals and their energy and protein requirements derived from the CAPRI database. The CAPRI database also indicates that there is a significant variation between Member States in mean excretion, suggesting that there is scope for lowering the protein content of the animal feed in at least some countries by 10 to 20% (Figure 13).

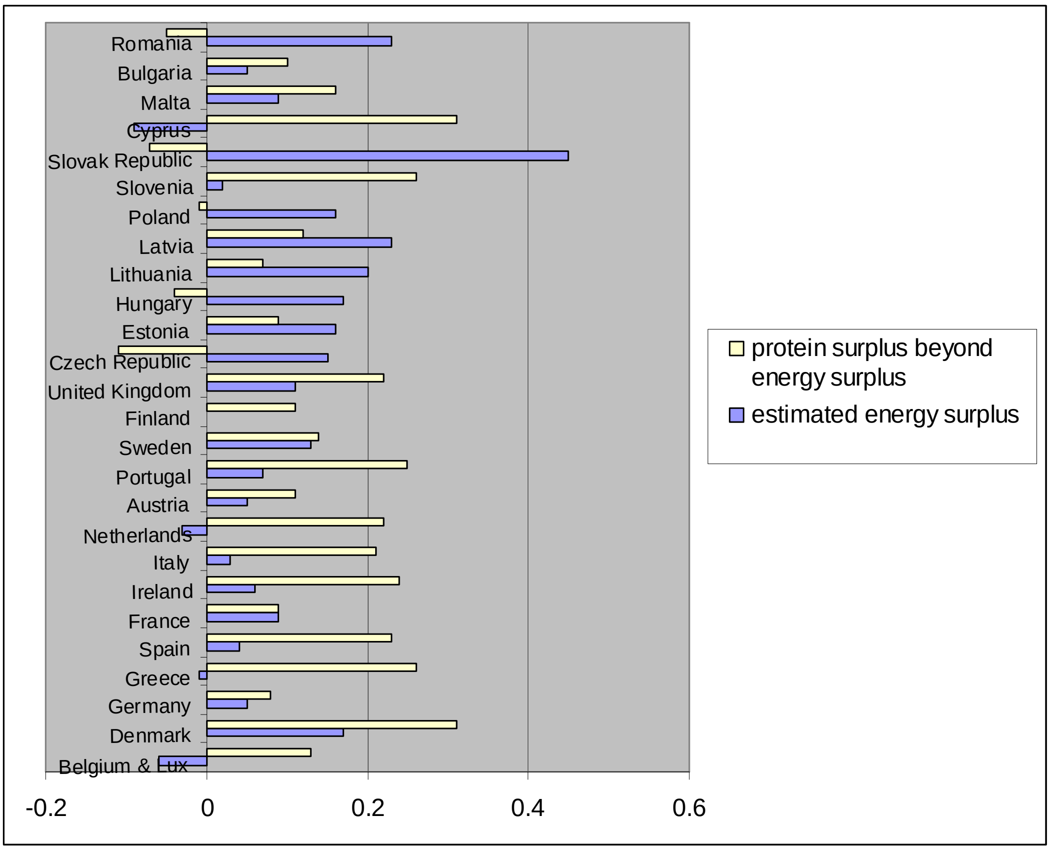

Figure 13. Protein surplus and energy surplus in animal production in European countries according to the CAPRI database.

As yet, it remains unclear which line of reasoning provides the most accurate assessment of the scope for low-protein animal feeding in the EU-27. Therefore, both lines of reasoning were used for scenario analyses. The first line of reasoning was used in the scenarios assessed by MITERRA-EUROPE (see Velthof et al., 2007). Based on the desk study presented in Chapter 3, it was assumed that the N excretion of dairy cattle, other cattle, pigs and poultry, as presented in the RAINS database can be decreased by on average 10% through a combination of low-protein animal feeding, and improved animal management, improved genetic potential of the herds and less replacement cattle. As a way of sensitivity analysis, a variant with 20% lower N excretion was included.

Table 21. Level of implementation (level of penetration, in %) of 'low-protein feeding' for dairy cattle, other cattle, pigs and poultry for each country included in the analysis for the years 2000, 2010 and 2020. Note that the year 2000 has been used as reference year (zero level implementation), though it is acknowledged that various farms have implemented some level of low-protein feeding already (see also text).

	2000				2010				2020			
Country	Dairy cattle	Other Cattle	Pigs	Poultry	Dairy cattle	Other cattle	Pigs	Poultry	Dairy cattle	Other cattle	Pigs	Poultry
AT	0	0	0	0	33	17	33	33	100	50	100	100
BG	0	0	0	0	17	8	17	17	50	25	50	50
BL	0	0	0	0	33	17	33	33	100	50	100	100
CR	0	0	0	0	25	13	25	25	75	38	75	75
CY	0	0	0	0	25	13	25	25	75	38	75	75
CZ	0	0	0	0	25	13	25	25	75	38	75	75
DE	0	0	0	0	33	17	33	33	100	50	100	100
DK	0	0	0	0	33	17	33	33	100	50	100	100
EE	0	0	0	0	17	8	17	17	50	25	50	50
EL	0	0	0	0	33	17	33	33	100	50	100	100
ES	0	0	0	0	33	17	33	33	100	50	100	100
FI	0	0	0	0	33	17	33	33	100	50	100	100
FR	0	0	0	0	33	17	33	33	100	50	100	100
HU	0	0	0	0	25	13	25	25	75	38	75	75
IR	0	0	0	0	25	13	25	25	75	38	75	75
IT	0	0	0	0	33	17	33	33	100	50	100	100
LT	0	0	0	0	17	8	17	17	50	25	50	50
LU	0	0	0	0	33	17	33	33	100	50	100	100
LV	0	0	0	0	17	8	17	17	50	25	50	50
MT	0	0	0	0	33	17	33	33	100	50	100	100
NL	0	0	0	0	33	17	33	33	100	50	100	100
PL	0	0	0	0	33	17	33	33	100	50	100	100
PT	0	0	0	0	33	17	33	33	100	50	100	100
RO	0	0	0	0	17	8	17	17	50	25	50	50
SE	0	0	0	0	33	17	33	33	100	50	100	100
SI	0	0	0	0	25	13	25	25	75	38	75	75
SK	0	0	0	0	25	13	25	25	75	38	75	75
TK	0	0	0	0	8	4	8	8	25	13	25	25
UK	0	0	0	0	33	17	33	33	100	50	100	100

As regards implementation of the low-protein animal feeding, two variants were considered, i.e., (i) on IPPC farms only, and (ii) on 'all' farms in EU-27, but the percentage implementation was different for different Member States (Table 21). These percentages were based on the general idea that 'knowledge' level of farmers is higher in the EU-15 than in the new Member States.

The second line of reasoning was used in the scenarios assessed by CAPRI. Here, the percentage decrease in N excretion was assessed by CAPRI, on the basis of the protein excess in the animal feed per Member States. Hence, country-specific and animal-type-specific assessments were made of the perspectives for lowering N excretion. However, because inaccurate recordings of feed quantities in the official data statistics might distort the nutrient balancing in CAPRI, safeguards have been introduced to prevent an exaggerated assessment of the avoidable protein excess:

- In case that both an energy surplus and a protein surplus is estimated it is assumed that the energy surplus is either indicative of general waste in feed use of the agricultural systems concerned (affecting both energy and protein), which is difficult to tackle or it is indicative of statistical problems. The 'avoidable' protein surplus has to be reduced in this case.
- A full removal of the observed protein surplus would imply that all farms in a country operate on the technology frontier of most efficient feeding practice, including, for example in the pig sector, multiphase feeding with fine tuned supplements of all amino acids in insufficient supply from the core feed ingredients. This is only achievable in experimental situations and evidently unrealistic for the vast majority of all farms.

It is proposed that low protein feeding be promoted through a combination of advisory services and financial incentives from agri-environmental measures. A 100% penetration will be difficult to achieve in this way. Table 21 above assumed that the knowledge level would develop sufficiently to achieve this in EU 15 countries but that in other countries penetration would be smaller. The energy surplus bars in Figure 4.2 support the assessment that surplus feeding may still be significant in current agriculture of the New Member States. If surplus feeding is significant there is also a large potential to avoid this through simple measures which can be implemented easily such as a reasonable assessment of the farmers own fodder. Hence, penetration rates in New Member States may be just as high as in EU15 countries. Prevalence of inefficiency also applies to non dairy cattle production such that applicability of low protein feeding may again be higher than indicated in Table 21 above if inefficiency may be reduced. For this analysis we have to acknowledge that future penetration rates are quite uncertain. In the CAPRI simulations we have assumed a typical penetration rate of 80% for all countries and activities in EU15 and a 70% penetration rate in other EU countries which is about the average in 2020 from Table 4.1, but gives a larger weight to the nitrogen saving 'potential' as opposed to the current 'knowledge' aspect.

These considerations are built into the Table 21b.

Table 21b. Achievable decrease in protein supply in animal feeding, as a function of the initial protein surplus and the calculated energy surplus for the 10% reduction scenario in EU15 countries

initial protein surplus → *initial energy surplus ↓*	*0.0%*	*10.0%*	*20.0%*	*30.0%*	*50.0%*
0.0%	0.0%	4.2%	8.5%	12.7%	21.2%
5.0%	0.0%	4.0%	**8.0%**	12.0%	20.0%
20.0%	0.0%	3.4%	6.8%	10.3%	17.1%
30.0%	0.0%	3.1%	6.2%	9.4%	15.6%
50.0%	0.0%	2.7%	5.3%	8.0%	13.3%

Table 21b is applied to all EU 15 countries and animal activities such that the differences in the initial estimate of the protein surplus determine the percentage decrease applied. For the typical case (see Figure 13) of a protein surplus of 20% combined with an estimated energy surplus of 5% we obtain a decrease of 8% which is downscaled from the full 10% decrease due to the assumed 80% penetration rate. A corresponding table has been applied in the New Member States, tailored to a somewhat lower typical penetration rate of 70%. For the more ambitious 20% decrease scenario a similar table has been used giving an effective decrease of about 15% for the typical case in EU15 (protein surplus = 20%, energy surplus = 5%). This acknowledges that penetration is likely to be a bit smaller if the measure is more ambitious (typical cases: 74% in EU15, 62% in New MS).

6.2. Description of the economic cost analyses

The implementation of low-protein animal feeding may cause different types of cost:

- Additional feed cost for optimized low protein compound feeds apply mainly on highly efficient farms.
- Additional costs for handling facilities related to several types of feed on a farm may apply if multi phase feeding is introduced.
- Additional time input of the farmer for improved planning of feed use will often be the main cost in New Member States and the ‘other cattle’ sector

In particular the time input is difficult to assess both in terms of hours as well as in terms of an appropriate wage rate (opportunity cost). For the CAPRI simulations we had to apply a workable hypothesis covering all countries and animal activities. The first idea underlying this hypothesis is that the costs are increasing if the relative decrease of the protein surplus increases. This relative decrease is simply the ratio of the decrease in protein supply from Table 21b to the initial protein surplus. It is assumed that additional costs go to infinity as the relative decrease approaches one (because perfect efficiency is unattainable) and that they are zero for a zero relative decrease. Furthermore the additional cost is expressed as a mark up of initial feed cost to incorporate differences between animal types and countries. The free parameter in the approximating formula has been chosen to give about 1.84 € per fattened pig or 29 € per dairy cow in terms of additional

feed cost under typical circumstances[1]. These costs are somewhat lower than in the December simulations in RAINS (about 3.3 € Euro per fattened pig, 55 € dairy cow) in view of the ongoing downward revision in RAINS. This is supported by information from German DVT representatives (FEFAC member) and from Dutch feed experts suggesting that the cost in RAINS may be somewhat exaggerated for current technologies and prices.
For the strong reduction scenario the effective cut comes close to 80% of the initial surplus which would bring farmers closer to the technological frontier (BAT). The additional costs would strongly increase therefore and amount to 9 € per fattened pig or 140 € per cow in the typical case in EU15. Even though this strong decrease is unlikely to be implemented in full it is nonetheless of interest for a sensitivity analysis. Figure 14 shows the implied cost curve in terms of relative changes.

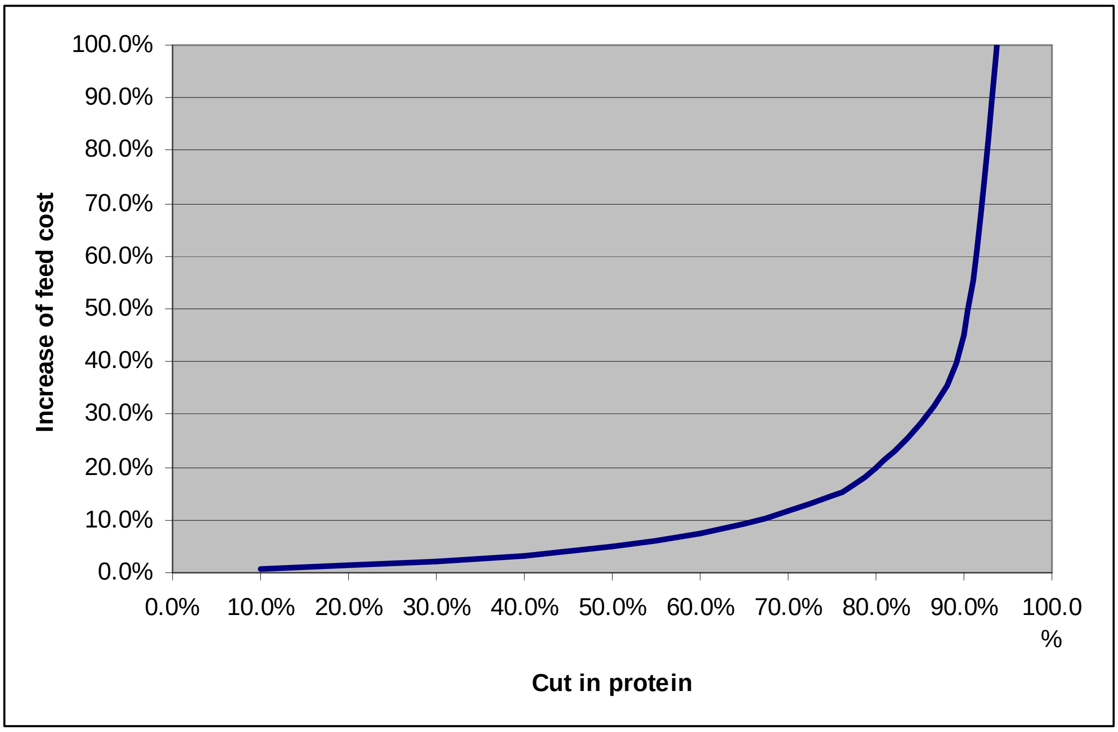

Figure 14. Relationship of relative increase in feed cost to relative reduction in protein supply to animals underlying the CAPRI simulations

[1] The formula is: c * relative cut / (1-relative cut) where c = 0.05. For a relative cut of 42% as in the first line of Table 4.2, we obtain a percentage increase of feed cost of 3.7% or 1.84 € if feed cost is 50 € (typical for fattening of pigs) or 29 € if feed cost is 800 € (case of dairy cows).

6.3. Description of the balanced fertilization scenario

The scope for improving N use efficiency in crop production and lowering N input in agriculture through balanced N fertilization was explored on the basis of the degree of balanced fertilization in the various Member States according to the results of MITERRA-EUROPE calculations. Currently, there is no consensus in literature about the definition of ‘balanced fertilization’. In MITERRA-EUROPE, balanced fertilization was defined in its most ‘straight’ form:

*Σ (input of available N from all sources) * EF = Σ (N output via harvested crop + crop residues).*

The factor EF is the crop specific efficiency factor that takes into account that crops are not able to take up all available N (see Chapter 4.3). The factor EF ranges between 1.00 and 1.25. The procedure for assessing balanced fertilization has been described in detail in Chapter 4 and in Velthof et al., 2007). The only difference is that balanced fertilization in the scenario ND full 2020 is applied to NVZs only, while it is considered applicable to all agricultural land in the current scenario (Balfert 2020). The assessment of balanced N fertilization was made by both MITERRA-EUROPE and CAPRI. Because MITERRA-EUROPE and CAPRI use slightly different approaches and definitions for balanced N fertilization, the results of both models may be seen as sensitivity analyses too.

In the CAPRI model, balanced fertilization implies basically an 80% decrease of the initial ‘overfertilisation’ (available N input / N output), taking into account that balanced fertilisation is already part of action programs for NVZ. This is a somewhat simplified and moderated version compared to the MITERRA-EUROPE calculations. However balanced fertilisation would require more careful establishments of fertiliser plans, more frequent soil analyses, perhaps split applications of fertiliser and more demanding crop management in general to bring about the increase in efficiency implied by a reduction in fertiliser input while maintaining output. Conceptually we should assess and value these additional management efforts which are not feasible however. Instead, we assumed a flat rate cost of 25 € per ha for a full elimination of overfertilisation (20 € for an 80% cut) which was meant to cover these management efforts. Different wage cost may have suggested to use higher costs in EU15 countries. However, the ‘knowledge argument’ from above could motivate that the required efforts would be higher in the New Member States. In view of transparency and lack of quantitative information we opted for the uniform flat rate assumption.

6.4. Description of the optimal combination scenario

The combination of balanced fertilization with a set of low-emission manure techniques for animal manure storage and application is considered to be the most optimal and far reaching scenario. The concept of balanced N fertilization applied here is similar to that described in Chapter 4 and applied in Chapter 6.3. Following consultation with the Commission, the National Projections baseline scenario for the revision of the NEC Directive, but optimized to achieve the targets of the Thematic Strategy in 2020

(RAINS optimized 2020 scenario) was chosen as feasible set of low-emission manure storage and application techniques. Hence, the 'optimal combination scenario' is a combination of RAINS optimized 2020 and Balfert 2020 and is the most far-reaching scenario.

The cost data for the optimised 2020 scenario are from RAINS except for the case of low nitrogen feeding and balanced fertilisation where the above assumptions have been applied in CAPRI.

An overview of the scenarios analyzed in Task 3 is presented in Table 23.

Table 23. Overview of the scenarios analyzed in Task 3 of the Ammonia Service Contract

Scenarios	Description
1. ND full 2020 (Reference scenario)	National Projections baseline scenario for the revision of the NEC Directive, 2020, plus full (strict) implementation of the N leaching abatement measures in extended areas of Nitrate Vulnerable Zones (Annex 1).
2. LNF 10%, all farms, 2020	ND full 2020 (see above) plus low-protein animal feeding that leads to a 10% decrease in N excretion, applied to all farms.
3. LNF 10%, IPPC farms, 2020	ND full 2020 (see above) plus low-protein animal feeding that leads to a 10% decrease in N excretion, applied to IPPC farms only
4. LNF 20%, all farms, 2020	ND full 2020 (see above) plus low-protein animal feeding that leads to a 20% decrease in N excretion, applied to all farms
5. LNF 20%, IPPC farms, 2020	ND full 2020 (see above) plus low-protein animal feeding that leads to a 20% decrease in N excretion, applied to IPPC farms only
6. Balfert 2020	ND full 2020 (see above) plus strict implementation of balanced N fertilization on all farms, irrespective of NVZs
7. Optimal Combination, 2020	Rains optimized 2020 (see Table 2.6) plus Balfert 2020

7. Results of the scenario analyses by MITERRA-EUROPE.

This chapter presents the results of the scenario analyses by the modeling tool MITERRA-EUROPE (see Velthof et al., 2007). A total of 6 scenarios and the reference scenario (ND full 2020) have been analysed (Table 23). Low-protein animal feeding has effect on the N excretion and thereby on the amount of N in animal manure. Balanced N fertilization (Balfert 2020) may have effect on the N fertilizer use and on the amount of manure N applied to agricultural land.

Table 24 shows the mean changes in the N inputs in agriculture of the EU-27. The LNF 10%, 2020 scenario decreases the amount of N in animal manure applied to land at EU-27 level by 6%, when applied on all farms, and by 1% when applied on IPPC farms only. Doubling the target for low-protein animal feeding to 20% decreases the amount of manure N by 13% and 3%, when applied on all farms and IPPC farms only, respectively. Balfert 2020 scenario and the Optimal Combination 2020 scenario have a large effect on the amount of manure N, especially in countries with no or a small area of NVZ in 2020. Fertilizer N input is not significantly affected by the LNF 10% and LNF 20% scenarios, but is greatly affected by the Balfert 2020 and the Optimal Combination 2020 scenarios. Again, the decreases are largest in countries with no or a small area of NVZ in 2020.

Table 24. Main N flows in agriculture in EU-27 in 2020 according to the ND full 2020 scenario, and the calculated potential changes relative to the ND full 2020 scenario for the LNF 10% on all farms scenario, the LNF 10% on IPPC farms scenario, the LNF 20% on all farms scenario, the LNF 20% on IPPC farms scenario, the Balfert 2020 scenario and the optimal combination scenario.

N source	ND full 2020	LNF 10% all	LNF 10% IPPC	LNF 20% all	LNF 20% IPPC	Balfert 2020	Optimal combination
	kton N	% change compared to ND full 2020					
Total N excretion	9887	-6	-1	-13	-3	0	-8
Applied N fertilizer	9212	1	0	3	0	-9	-7
Applied manure N	4341	-7	-1	-13	-3	-6	-13
N excreted during grazing	3271	-4	0	-8	-1	0	-6
N deposition	1896	-2	0	-5	-1	0	-7
Biological fixation	823	0	0	0	0	0	0

As discussed also in Velthof et al. (2007), strict interpretation of balanced fertilization has a large influence on the N input via N fertilizer and animal manure N (Table 24). The decreases in animal manure N in the Balfert 2020 scenario do not pertain to the manure from grazing animals (N excretion by grazing animals does not decrease in the Balfert scenario). In practice, decreasing the N input via fertilizer N and applied animal manure N to grazed grasslands, as in the Balfert 2020 scenario, will likely decrease the protein content of the herbage. However, such a feedback is not yet included in MITERRA-EUROPE.

The decrease in applied N via animal manure in the Balfert 2020 scenario (Table 24) implicitly assumes that some manure N has to be disposed elsewhere. As discussed also in

Chapter 2, the decrease in animal manure N brought about by balanced fertilization will require a combination of low-protein animal feeding and manure treatment. This suggest that full implementation of 'balanced N fertilization', as defined here, will need at the same time implementation of 'low-protein animal feeding' to be able to decrease the N excretion by the animals to the level that the manure N can be 'absorbed'.

Because of the changes in the amounts of excreted N and in the applications of manure N and fertilizer N to agricultural land, leaching losses decrease significantly (Table 25). Total decreases in leaching are largest in the Optimal Combination 2020 scenario. Note that the LNF scenarios have a relative large influence on the leaching losses from manure storage.

Table 25. Total N leaching losses from agriculture to groundwater and surface waters in EU-27 according to the ND full 2020 scenario, and the calculated potential changes relative to the ND full 2020 scenario for the LNF 10% on all farms scenario, the LNF 10% on IPPC farms scenario, the LNF 20% on all farms scenario, the LNF 20% on IPPC farms scenario, the Balfert 2020 scenario and the optimal combination scenario.

Leaching pathway	ND full 2020	LNF 10% all	LNF 10% IPPC	LNF 20% all	LNF 20% IPPC	Balfert 2020	Optimal combination
	kton N	% change compared to ND full 2020					
Manure storage	160	-7	-2	-15	-4	0	-8
Surface runoff	657	-2	0	-4	-1	-6	-8
Small surface water and groundwater	1025	-4	-1	-8	-2	-15	-19
Large surface water	66	-5	-1	-9	-2	-14	-18
Total	1908	-4	-1	-7	-2	-11	-14

The decrease in N input via animal manure and fertilizer in the LNF, Balfert and Optimal Combination 2020 scenarios have a strong effect on the emissions of NH_3, N_2O, NO_X and CH_4 to the atmosphere and the leaching of N to groundwater and surface waters. Figure 15 provides an overview of the changes in the emissions of NH_3, N_2O and NO_X and the leaching of N in these scenarios. Decreases are equally large for NH_3 and N_2O emissions and the leaching of N. Decreases in emissions and leaching are large for the scenarios LNF 20% on all farms 2020, Balfert 2020, and Optimal Combination 2020. Effects of the scenarios LNF 10% and LNF 20% applied to IPPC farms in 2020 only are relatively small.

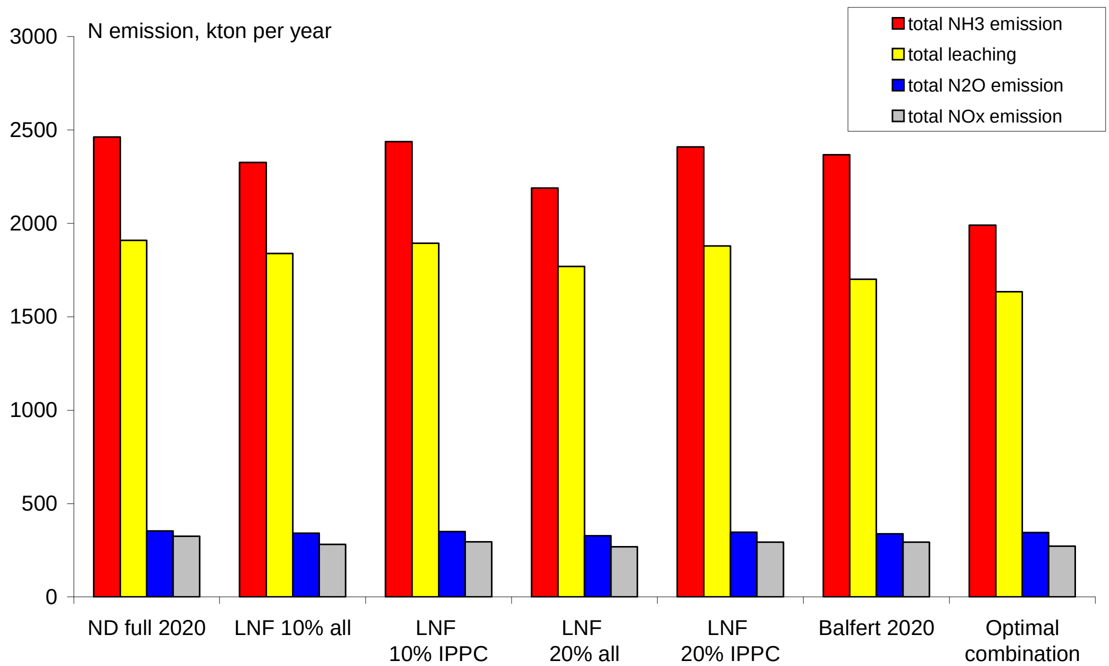

Figure 15. Gaseous N losses and N leaching losses from agriculture in the ND full 2020 reference scenario and the LNF, Balfert 2020 and Optimal combination 2020 scenarios.

The ND full 2020 scenario was chosen as the reference scenario. Emissions of NH_3 in the ND full 2020 scenario are 14% lower compared to the reference year 2000 (Velthof et al., 2007). The estimated total NH_3 emission from agriculture in this scenario are 2989 kton per year in the EU-27 (Table 26), which is roughly ~300 kton NH_3 per year above the calculated emission level in the EU-27 (see Aman et al., 2006b) to achieve the targets of the Thematic Strategy on Air Pollution for NH_3 .

Table 26. Ammonia emission in 2000 for EU-27 in kton NH_3, according to the ND full 2020 scenario, and the calculated changes relative to the ND full 2020 scenario for the LNF 10% on all farms scenario, the LNF 10% on IPPC farms scenario, the LNF 20% on all farms scenario, the LNF 20% on IPPC farms scenario, the Balfert 2020 scenario and the optimal combination scenario.

Country	ND full 2020	LNF 10% all	LNF 10% IPPC	LNF 20% all	LNF 20% IPPC	Balfert 2020	Optimal combination
	kton NH3	% change compared to ND full 2020					
EU-27	2989	-6	-1	-11	-2	-4	-19
Austria	51	-8	0	-15	0	0	-29
Belgium	65	-6	-1	-13	-1	0	-11
Bulgaria	33	-3	0	-5	0	0	-6
Cyprus	5	-6	-3	-11	-5	-25	-39
Czech. Rep	70	-4	-3	-9	-7	-1	-12
Denmark	68	-4	1	-12	0	0	-29
Estonia	9	-4	-3	-8	-6	0	-17
Finland	21	-7	0	-14	-1	0	-14
France	507	-6	-1	-10	-1	-6	-26
Germany	390	-6	-1	-13	-2	0	-11
Greece	38	-4	-1	-7	-2	-11	-26
Hungary	73	-5	-3	-10	-6	-4	-28
Ireland	83	-4	0	-8	-1	0	-19
Italy	341	-5	-1	-11	-3	-5	-18
Latvia	13	-4	-1	-7	-2	0	-29
Lithuania	31	-3	-1	-6	-2	0	-22
Luxembourg	3	-6	0	-12	0	0	-28
Malta	2	-5	0	-10	0	-30	-34
Netherlands	114	-7	-1	-14	-2	0	-11
Poland	281	-6	-1	-13	-2	-8	-21
Portugal	48	-6	-2	-13	-3	-14	-34
Romania	129	-3	0	-6	0	0	-7
Slovakia	27	-5	-3	-11	-6	0	-14
Slovenia	18	-5	0	-10	-1	0	-36
Spain	299	-6	-1	-11	-2	-9	-26
Sweden	41	-8	-1	-15	-2	-2	-11
United Kingdom	228	-6	-2	-12	-4	-1	-15

The LNF 10% 2020 scenario decreases the emissions of NH_3 at EU-27 level by 6% relative to the ND full 2020 reference scenario, when applied on all farms, and by 1% when applied on IPPC farms only. Doubling the target for low-protein animal feeding to 20% decreases the emissions of NH_3 by 11% and 2%, when applied on all farms and IPPC farms only, respectively (Table 26). Clearly, the projected 10% decrease in the emissions of NH_3 in the LNF 20% 2020 on all farms, relative to the ND full 2020 scenario, greatly contributes to achieving the target of the Thematic Strategy on Air Pollution. However, differences between Member States are large.

The Balfert 2020 scenario decreases total NH_3 emissions by 4% relative to the ND full 2020 reference scenario (Table 26). The Optimal Combination 2020 scenario has a much larger effect on the emissions of NH_3 (Table 26) especially in countries with no or a small area of NVZ in 2020; it decreases the NH_3 emissions by 19%.

Table 27. Leaching losses of N in 2000 for EU-27 in kton N, according to the ND full 2020 scenario, and the calculated potential changes relative to the ND full 2020 scenario for the LNF 10% on all farms scenario, the LNF 10% on IPPC farms scenario, the LNF 20% on all farms scenario, the LNF 20% on IPPC farms scenario, the Balfert 2020 scenario and the optimal combination scenario.

Country	ND full 2020	LNF 10% all	LNF 10% IPPC	LNF 20% all	LNF 20% IPPC	Balfert 2020	Optimal combination
	kton N	% change compared to ND full 2020					
EU-27	1908	-4	-1	-7	-2	-11	-14
Austria	14	-6	0	-12	0	0	-7
Belgium	41	-4	0	-9	-1	0	-5
Bulgaria	40	-2	0	-4	0	-2	-6
Cyprus	4	-4	-2	-7	-4	-37	-40
Czech. Rep	77	-3	-3	-7	-6	-3	-7
Denmark	41	-3	0	-11	-1	0	-2
Estonia	5	-5	-4	-11	-9	0	-10
Finland	5	-2	0	-3	0	0	-1
France	372	-3	0	-6	-1	-16	-19
Germany	215	-2	0	-4	-1	0	-3
Greece	23	-2	0	-4	-1	-13	-14
Hungary	78	-3	-2	-5	-3	-16	-18
Ireland	34	-7	0	-15	-1	0	-13
Italy	159	-4	-1	-7	-2	-13	-16
Latvia	10	-3	-1	-7	-2	-1	-7
Lithuania	22	-3	-1	-6	-2	0	-5
Luxembourg	3	-3	0	-5	0	0	-2
Malta	1	-4	0	-8	0	-46	-48
Netherlands	69	-5	-1	-10	-2	0	-5
Poland	222	-5	-1	-9	-1	-24	-27
Portugal	24	-6	-2	-11	-3	-27	-29
Romania	74	-4	0	-7	0	-1	-9
Slovakia	13	-5	-4	-11	-7	0	-7
Slovenia	5	-2	0	-5	0	0	1
Spain	168	-4	-1	-9	-2	-21	-23
Sweden	9	-5	-1	-9	-1	-8	-13
United Kingdom	181	-4	-1	-7	-2	-6	-10

The N leaching losses (Table 27) decrease in all scenarios examined in this task. The LNF 10% 2020 scenario decreases N leaching losses at EU-27 level by 4% relative to the ND full 2020 reference scenario, when applied on all farms, and by less than 1% when applied on IPPC farms only. Doubling the target for low-protein animal feeding to 20% decreases the N leaching losses by 7% and 2%, when applied on all farms and IPPC farms only, respectively. The Balfert 2020 scenario and the Optimal Combination 2020 scenario have large effects on the N leaching losses, especially in countries with no or a small area of NVZ in 2020. Balfert 2020 decreases the N leaching losses by 11% and the Optimal Combination 2020 scenarios by 14% relative to the reference scenario ND full 2020.

The N_2O emissions (Table 28) decrease also in all scenarios examined in this task. The LNF 10% 2020 scenario decreases the emissions of N_2O at EU-27 level by 4% relative to the ND full 2020 reference scenario, when applied on all farms, and by 1% when applied on IPPC farms only. Doubling the target for low-protein animal feeding to 20% decreases the emissions of N_2O by 7% and 2%, when applied on all farms and IPPC farms only, respectively. The Balfert 2020 scenario decreases the emissions of N_2O by 4% and the Optimal Combination 2020 scenarios by 3% relative to the reference scenario ND full 2020. Differences between Member States are large.

Table 28. Nitrous oxide emissions in 2000 for EU-27 in kton N_2O-N, according to the ND full 2020 scenario, and the calculated potential changes relative to the ND full 2020 scenario for the LNF 10% on all farms scenario, the LNF 10% on IPPC farms scenario, the LNF 20% on all farms scenario, the LNF 20% on IPPC farms scenario, the Balfert 2020 scenario and the optimal combination scenario.

Country	ND full 2020	LNF 10% all	LNF 10% IPPC	LNF 20% all	LNF 20% IPPC	Balfert 2020	Optimal combination
	kton N	% change compared to ND full 2020					
EU-27	354	-4	-1	-7	-2	-4	-3
Austria	4	-5	0	-10	0	0	10
Belgium	7	-4	-1	-8	-1	0	-1
Bulgaria	5	-2	0	-3	0	0	-4
Cyprus	1	-4	-3	-8	-5	-24	-22
Czech. Rep	9	-3	-3	-7	-6	-1	-2
Denmark	8	-3	0	-8	-1	0	5
Estonia	1	-3	-3	-6	-5	0	-1
Finland	3	-3	0	-5	-1	0	3
France	62	-4	0	-7	-1	-6	0
Germany	43	-3	-1	-6	-1	0	-2
Greece	7	-1	0	-3	-1	-7	-4
Hungary	11	-3	-2	-7	-4	-8	0
Ireland	12	-3	0	-6	-1	0	-2
Italy	31	-4	-1	-8	-3	-5	-5
Latvia	1	-3	-1	-5	-1	0	11
Lithuania	3	-2	-1	-4	-2	0	6
Luxembourg	0	-3	0	-6	0	0	8
Malta	0	-4	0	-9	0	-35	-39
Netherlands	15	-5	-2	-11	-4	0	-3
Poland	30	-5	-1	-10	-2	-12	-12
Portugal	5	-5	-1	-10	-3	-12	-2
Romania	15	-2	0	-5	0	0	-5
Slovakia	3	-4	-3	-7	-5	0	-2
Slovenia	1	-3	0	-6	0	0	14
Spain	34	-4	-1	-8	-2	-10	-4
Sweden	5	-4	-1	-8	-2	-5	-8
United Kingdom	36	-4	-1	-7	-3	-2	-3

The CH_4 emissions from agriculture (not shown) were only slightly (changes < 1%) affected in scenarios examined in this task. The non-response is related to the facts that the number of (ruminant) animals do not change in the LNF 2020, Balfert 2020and Optimal Combination 2020 scenarios, relative the reference scenario ND full 2020, and that MITERRA-EUROPE does not account for possible effects of low-protein animal feeding on CH_4 emissions.

Summarizing, the results of the scenarios analysed in this chapter clearly indicate that both low-protein animal feeding and balanced N fertilization and an optimal combination of NH_3 emission abatement techniques with balanced N fertilization have synergistic effects and decrease the emissions of N_2, NH_3, N_2O and NO_x to the atmosphere and of N leaching to groundwater and surface waters simultaneously. Hence, no pollution swapping occurs. Further, balanced N fertilization has larger effects on N losses via leaching and denitrification than on N losses via the emissions of NH_3, N_2O and NO_x. Low-protein animal feeding has a rather steady and constant effect on all N loss pathways. It decreases the amount of N in animal manure (Table 24).

Implementation of balanced N fertilization as defined in this study decreases N fertilizer use (Table 24), and in some areas also the amounts of applied manure N. As indicated before, it is assumed that the decrease of applied manure N is 'treated and taken out of agriculture' or 'not produced to low-protein animal feeding'. Evidently, these assumptions have large implications for agriculture. In general, lowering the amount of manure N via low-protein animal feeding has lower costs than treatment and disposal of the manure N to elsewhere. However, lowering the protein-content of the animal feed requires investments in knowledge and feed technology.

8. Results of the scenario analyses by CAPRI

The scenarios indicated in Table 23 have also been calculated with CAPRI except for the scenario ‘LNF 20% applied to IPPC farms only’. The scenario ‘LNF 20% applied to IPPC farms only’ is considered to be somewhat “optimistic” (unrealistic) on a relatively short term, because it may be expected that IPPC farms are already quite efficient in the current situation (near the technical limit).

The CAPRI results provide an integrated assessment of economic and environmental impacts. Both, the economic and environmental impacts of a scenario are presented in one table. The impacts will be given for:

- Agricultural income;
- Gaseous emissions (NH_3, N_2O, CH_4) to the atmosphere and leaching of N to groundwater and surface waters; and
- Other affected variables of interest (mineral fertiliser, selected activity levels).

We begin with a brief discussion of the impacts of the full implementation of the Nitrates Directive (ND) in 2020 compared to a hypothetical situation in 2020 with partial implementation of the ND and delineation of NVZs as currently (Table 29). This scenario is mainly reported to explain the mode of implementation of the ND in the CAPRI model and to identify impacts of the implementation of the ND in isolation.

The CAPRI simulation gives impacts where the current implementation of the ND is incomplete. This is considered to be not more than 25% of the full potential currently, depending on the country. Furthermore there will be impacts where the NVZs are extended in geographical terms. Impacts are visible in a decrease in the mineral fertilizer use and in an increase of ‘other’ costs. Savings in mineral fertilizer purchases may compensate somewhat for the additional management effort which is indicated in column 'net direct costs', giving the difference of additional managerial effort (simplified assumption from Section 6.3: 25 € / ha for a 100% implementation in year 2000 prices) and the savings in mineral fertilizer purchases. In Belgium and in the Netherlands the savings are estimated to exceed the additional managerial effort based on our (simplified) assumptions. The impact on agricultural income is the net effect of these changes, slightly modified by any other changes in activity levels or input demand. Such changes are limited to the crop sector in this case of the ND full 2020 scenario and they mainly affect pulses (-1% for EU27) and (less) soy beans. This decline may be explained in two ways. The balanced fertilization (which is the main effect of the ND in CAPRI) increases the efficiency of fertilizer use and thus the relative profitability of N consuming crops compared to pulses (and soy beans). Alternatively, the scenario may be viewed as a forced reduction in N application which again operates against pulses. Excretion is not affected by this scenario such that the environmental impacts are also due to the changed use of mineral fertilizers.

The regional variation of impacts in this scenario is mainly caused by three factors:

1) Impacts tend to be the larger the larger is the shares of the area covered by NVZ. This explains for example stronger impacts in Slovenia as opposed to the Czech Republic (both with sizable overfertilisation) or in Lithuania compared to Poland (both with moderate overfertilisation).
2) Comparing the Netherlands with Denmark or Germany (all with 100% NVZ) shows the effect of a higher initial overfertilisation.
3) Comparing Germany and Austria the share of N from mineral fertiliser is much higher in the former country such that a smaller reduction is sufficient to meet balanced fertilisation targets. This effect also explains quite large impacts of the implementation of the ND in Slovenia.

In the following discussion we will focus on the impacts relative to the ND full 2020 scenario and give results in terms of absolute changes and percentage changes as both can be interesting depending on the question.

The implementation of **balanced fertilization** in the whole area would have effects where the area was not covered by NVZs before. As a consequence this is manly a regional extension of the ND full 2020 scenario to additional areas, at least in the CAPRI simulations where locally and temporarily relevant requirements of the ND (for sloping soils, winter months) are simply ignored.

Overall the CAPRI simulation gives a 9% decrease in EU27 mineral fertilizer use compared to the ND full reference situation. Impacts on mineral fertiliser use tend to be larger (i) the smaller the initial NVZ share, (ii) the larger the initial overfertilisation, and (iii) the smaller the share of mineral fertiliser in total N supply.

In terms of regional variation we have to admit that the data situation in Cyprus and Malta is quite difficult and that the percentage declines of 86% and 51% in Table 30 are overstated. CAPRI does include some safeguards in the form of minimum requirements from mineral fertilizer but these safeguards turned out to have loopholes for the particular situation of these countries.

Agricultural income is expected to decline by about 1.5% or 3.1 billion €. Acknowledging the uncertainties in these simulations this gives for a Euro of income loss about 50 g less leaching, 20 g less NH_3 emissions and 6 g less N_2O emissions.

Table 29. Simulation results of CAPRI for the scenario ND full 2020 versus the scenario ND partial 2020.

Absolute change ND full 2020 vs. ND partial 2020

	agric income [m €]	'other' costs [m €]	'net' dir cost [m €]	mineral fertiliser [kton N]	excretion [kton N]	total NH3 loss [kton N]	total CH4 emisions [kton N]	total N2O emisions [kton N]	leaching [kton N]
EU27	-1691	2563	1727	-951	2	-26	2	-20	-223
Austria	-79	94	81	-17	0	1	0	0	-2
Belgium	14	28	-12	-36	0	0	0	-1	-15
Bulgaria	0	0	0	0	0	0	0	0	0
Cyprus	0	0	0	0	0	0	0	0	0
Czech. Rep	-58	73	58	-29	0	-1	0	-1	-10
Denmark	-66	78	65	-14	0	0	0	0	-7
Estonia	-2	2	2	0	0	0	0	0	0
Finland	-39	74	39	-33	0	0	0	-1	-2
France	-264	388	260	-124	0	-3	0	-2	-25
Germany	-415	512	414	-114	0	-3	0	-2	-28
Greece	-30	36	31	-6	0	0	0	0	-1
Hungary	-94	114	94	-28	0	-1	0	-1	-6
Ireland	-101	146	105	-49	1	-1	1	-1	-10
Italy	-118	147	111	-45	0	-2	0	-1	-8
Latvia	-6	7	6	-1	0	0	0	0	0
Lithuania	-78	100	78	-26	0	-1	0	-1	-9
Malta	0	0	0	0	0	0	0	0	0
Netherlands	6	60	2	-63	0	-2	0	-1	-24
Poland	-9	12	10	-3	0	0	0	0	-1
Portugal	-14	16	13	-3	0	0	0	0	0
Romania	-1	0	0	0	0	0	0	0	0
Slovakia	-20	23	20	-5	0	0	0	0	-2
Slovenia	-13	21	13	-11	0	0	0	0	-2
Spain	-118	181	122	-81	0	-5	0	-2	-12
Sweden	-21	38	21	-14	0	0	0	0	-1
United Kingdom	-168	413	196	-249	1	-5	1	-6	-60

Percentage change ND full 2020 vs. ND partial 2020

	agric income [%]	'other' costs [%]	'net' dir cost [%]	mineral fertiliser [%]	excretion [%]	total NH3 loss [%]	total CH4 emisions [%]	total N2O emisions [%]	leaching [%]
EU27	-1	8	4	-8	0	-1	0	-3	-18
Austria	-3	11	8	-16	0	1	0	-2	-25
Belgium	0	7	-2	-22	0	-1	0	-4	-23
Bulgaria	0	0	0	0	0	0	0	0	0
Cyprus	0	0	0	0	0	0	0	0	0
Czech. Rep	-3	16	8	-8	0	-3	0	-4	-24
Denmark	-2	8	6	-7	0	0	0	-2	-15
Estonia	-1	7	4	0	0	0	0	0	-1
Finland	-3	9	4	-24	0	-1	0	-11	-46
France	-1	7	3	-5	0	-1	0	-2	-13
Germany	-2	10	5	-6	0	-1	0	-2	-19
Greece	0	17	7	-3	0	-1	0	-1	-7
Hungary	-2	14	7	-6	0	-1	0	-2	-19
Ireland	-4	29	12	-16	0	-1	0	-4	-26
Italy	0	5	3	-6	0	-1	0	-1	-10
Latvia	-2	11	5	-2	0	0	0	-1	-5
Lithuania	-11	114	28	-19	0	-6	0	-6	-45
Malta	0	0	0	0	0	0	0	0	0
Netherlands	0	2	0	-26	0	-2	0	-5	-26
Poland	0	4	1	0	0	0	0	0	-1
Portugal	0	1	1	-3	0	0	0	-1	-4
Romania	0	0	0	0	0	0	0	0	0
Slovakia	-3	8	5	-4	0	-1	0	-2	-16
Slovenia	-2	43	15	-36	0	-1	0	-9	-45
Spain	0	13	5	-9	0	-2	0	-2	-11
Sweden	-1	4	2	-8	0	0	0	-2	-24
United Kingdom	-2	11	4	-24	0	-2	0	-7	-33

Table 30: Simulation results of CAPRI for the scenario balanced fertilization (Balfert 2020) vs. ND full 2020

Absolute change Balfert vs. ND full 2020

	agric income [m €]	'other' costs [m €]	'net' dir cost [m €]	mineral fertiliser [kton N]	excretion [kton N]	total NH3 loss [kton N]	total CH4 emisions [kton N]	total N2O emisions [kton N]	leaching [kton N]
EU27	-3058	3877	3103	-888	-1	-53	-1	-19	-157
Austria	0	0	-1	0	0	0	0	0	0
Belgium	12	22	-11	-25	0	-1	0	-1	-7
Bulgaria	-136	198	140	-40	0	-2	0	-1	-9
Cyprus	2	5	-6	-7	-1	0	0	0	-1
Czech. Rep	-95	118	97	-41	0	-2	0	-1	-11
Denmark	2	0	-1	0	0	0	0	0	0
Estonia	-26	27	26	-1	0	0	0	0	0
Finland	0	0	0	0	0	0	0	0	0
France	-358	500	366	-127	0	-6	0	-3	-28
Germany	2	0	-4	0	0	0	0	0	0
Greece	-180	199	182	-22	0	-1	0	0	-2
Hungary	-110	139	114	-36	0	-1	0	-1	-6
Ireland	-4	2	4	-1	0	0	0	0	0
Italy	-359	436	356	-95	0	-9	0	-2	-16
Latvia	-42	47	43	-5	0	0	0	0	-1
Lithuania	2	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0
Netherlands	-2	0	-1	0	0	0	0	0	0
Poland	-506	605	526	-142	0	-10	0	-3	-25
Portugal	-115	140	116	-25	0	-1	0	-1	-3
Romania	-529	576	527	-47	0	-3	0	-1	-10
Slovakia	-31	37	33	-6	0	0	0	0	-1
Slovenia	0	0	0	0	0	0	0	0	0
Spain	-482	660	491	-209	-1	-16	0	-4	-27
Sweden	-37	53	37	-13	0	0	0	0	-1
United Kingdom	-67	113	67	-46	0	-1	0	-1	-8

Percentage change Balfert vs. ND full 2020

	agric income [%]	'other' costs [%]	'net' dir cost [%]	mineral fertiliser [%]	excretion [%]	total NH3 loss [%]	total CH4 emisions [%]	total N2O emisions [%]	leaching [%]
EU27	-1.5	11.2	2.6	-8.6	0.0	-1.8	0.0	-2.6	-15.0
Austria	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
Belgium	0.3	5.5	-0.3	-19.4	0.0	-0.7	0.0	-3.2	-14.4
Bulgaria	-5.1	76.9	14.3	-20.1	0.0	-4.3	0.0	-7.5	-49.6
Cyprus	0.5	11.2	-3.1	-86.4	-2.4	-10.5	-1.5	-16.3	-43.4
Czech. Rep	-5.4	22.5	6.1	-12.3	0.0	-4.8	0.0	-6.2	-36.5
Denmark	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Estonia	-12.4	84.5	16.2	-5.6	0.1	-0.6	0.1	-2.0	-7.7
Finland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
France	-1.1	8.1	1.6	-5.9	0.0	-1.2	0.0	-2.2	-16.1
Germany	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Greece	-1.7	82.1	10.1	-11.5	0.0	-2.6	0.0	-4.0	-20.9
Hungary	-2.8	14.6	3.9	-8.2	0.0	-2.0	0.1	-3.4	-24.5
Ireland	-0.1	0.3	0.1	-0.3	0.0	0.0	0.0	0.0	-0.4
Italy	-1.0	13.8	3.1	-12.9	0.0	-2.5	0.0	-3.5	-20.3
Latvia	-16.3	66.1	19.1	-11.3	0.0	-3.1	0.0	-3.3	-23.3
Lithuania	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malta	0.5	5.1	-1.1	-51.0	0.0	0.0	0.0	-11.1	-15.8
Netherlands	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	-0.1
Poland	-5.9	183.1	11.6	-14.3	-0.1	-4.0	-0.1	-4.8	-29.7
Portugal	-2.9	11.5	3.8	-24.4	0.0	-2.5	-0.1	-4.9	-26.3
Romania	-9.4	41.4	13.2	-9.8	0.0	-3.2	0.0	-3.4	-26.6
Slovakia	-4.6	12.0	4.5	-5.5	0.0	-1.3	0.0	-2.3	-13.9
Slovenia	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spain	-1.2	43.2	4.3	-27.0	0.0	-4.9	0.0	-6.2	-27.1
Sweden	-2.4	5.8	1.7	-7.8	0.0	-0.3	0.0	-2.6	-23.4
United Kingdom	-0.7	2.7	0.7	-5.6	0.0	-0.6	0.0	-1.4	-6.6

The regional variation of agricultural income effects in the scenario balanced fertilization relative to the ND full 2020 reference is shown in the Figure 16. It is evident that the percentage losses are lowest where NVZs were enforcing balanced fertilization already in the reference situation (green = gains in income, losses increasing with red colour). Other factors such as the economic weight of the crop sector operate to modify these impacts but appear to be less important than the initial NVZ share.

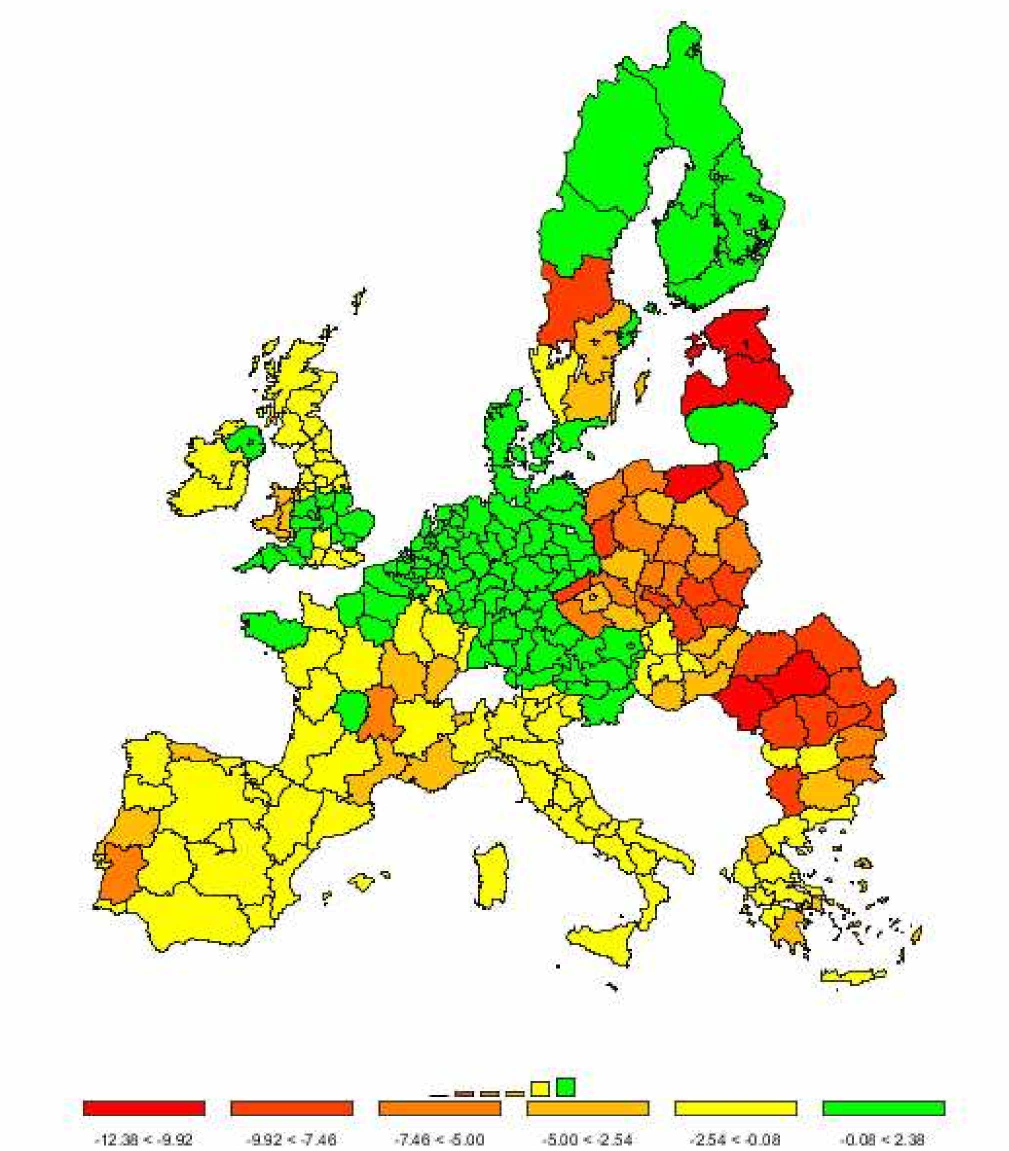

Figure 16. Regional variation of percentage income effects for scenario BALFERT relative to ND full 2020. (Bars illustrate the distribution)

Table 31 gives the changes of main components of agricultural income from scenario BALFERT.

Table 31: Contributions to agricultural income according to CAPRI simulations for the scenario balanced fertilization (Balfert 2020) vs. ND full 2020

	EAA value [million €]	Unit value EAA [€ / t]	Quantity [1000 t]	EAA value [change]	Unit value EAA [change]	Quantity [change]
European Union 27						
Production value	426383			0.0%		
Cereals	35863	106	339507	0.0%	0.2%	-0.2%
Other non fodder	157162	252	624354	0.0%	0.0%	0.0%
Fodder	18944	9	2144968	0.1%	0.0%	0.1%
Meat	74266	1616	45947	0.0%	0.0%	0.0%
Other Animal products	59045	271	217684	-0.1%	-0.1%	0.0%
Other output	81103	164	494052	0.1%	0.1%	0.0%
Inputs	261324			1.2%		
Fertiliser	39283	819	47951	-1.7%	0.0%	-1.7%
Feedingstuff	72481	47	1545314	-0.1%	-0.2%	0.1%
Other input	149560	281	532491	2.6%	2.1%	0.5%
European Union 15						
Production value	370370			0.0%		
Cereals	26627	111	240085	0.0%	0.0%	0.0%
Other non fodder	140660	263	534942	0.0%	0.0%	0.0%
Fodder	15813	9	1767083	0.1%	0.0%	0.1%
Meat	64587	1682	38401	0.0%	0.0%	0.0%
Other Animal products	50905	276	184382	-0.1%	-0.1%	0.0%
Other output	71777	173	413886	0.0%	0.0%	0.0%
Inputs	224756			0.7%		
Fertiliser	31818	850	37423	-1.4%	0.0%	-1.4%
Feedingstuff	63094	48	1325855	-0.1%	-0.1%	0.1%
Other input	129845	289	448615	1.6%	1.3%	0.3%
European Union 12						
Production value	56013			0.0%		
Cereals	9236	93	99422	-0.1%	0.4%	-0.5%
Other non fodder	16502	185	89412	0.0%	0.1%	-0.1%
Fodder	3131	8	377885	0.1%	0.1%	0.0%
Meat	9679	1283	7546	0.0%	0.1%	-0.1%
Other Animal products	8140	244	33302	-0.1%	0.0%	0.0%
Other output	9326	116	80166	0.3%	0.4%	-0.1%
Inputs	36567			4.1%		
Fertiliser	7465	709	10528	-2.9%	-0.1%	-2.8%
Feedingstuff	9387	43	219458	-0.1%	-0.3%	0.2%
Other input	19715	235	83876	8.7%	7.4%	1.3%

It is evident that the impacts of this scenario are estimated to be quite small both in the crop and livestock sector. The impact on fertiliser is much smaller than the 9% reduction mentioned above first because non nitrogen fertilisers are not directly affected and more importantly because the fertiliser value and quantity given in Table 31 includes the imputed value *plant available manure* (both on the input and output side). The increase in 'other input' mainly derives from our assumptions on additional management effort needed to bring about this change in agricultural farming practice.

The change in agricultural income is one component of the total change in ‘economic welfare’ (Table 32)

Table 32: Contributions to the change in conventional economic welfare according to CAPRI simulations for the scenario balanced fertilization (Balfert 2020) vs. ND full 2020 [million €]

	EU27	EU15	EU12
Total	-3056	-1559	-1497
Consumer money metric	-26	-9	-17
Agricultural income	-3058	-1588	-1470
Premiums	12	1	11
Agricultural Output	52	38	15
Output crops	27	37	-10
Output animals	25	0	25
Output rest	0	0	0
Agricultural Input	3123	1626	1496
Crop specific Input	-679	-456	-223
Animal specific Input	-42	-37	-5
Other Input	3844	2119	1725
'Net' direct cost	3103	1603	1500
Profit of dairies	-1	-1	0
Profit of other processing	34	36	-2
Tariff revenues	-2	-6	4
FEOGA first pillar	3	-8	11

In this scenario, consumers, the processing industry and the budget are hardly affected such that the total welfare effect is almost equal to the impact on agriculture. Note that the budget impacts do not include estimated for the required additional efforts of the public advisory system such that the above welfare cost is underestimated to some extent. However, note also that the benefits of this and other scenarios in terms of reduced emissions have not been monetised. Finally the row ‘net’ direct cost shows that in this scenario the total welfare effects are almost identical to the ‘net’ direct cost, i.e. the additional costs for higher managerial effort net of the savings in fertiliser cost. This is to be expected if the price effects are very small.

Low-protein animal feeding as measure to decrease N excretion will be promoted through agri-environmental programs and additional advisory work. It is assumed that farmers do not compensate the decrease in N supply to crops, following the decrease in the N content of the animal manure, through increased application of mineral fertilizers. Everything else equal, mineral N fertilizer use would be more or less constant therefore following implementation of low-protein animal feeding.

However, increased efficiency in protein use also implies that protein need is decreasing which would lead to some substitution among fodder types. Protein rich feed decreases in use and some others also increase. Among the protein rich feed is grass which is partly replaced with other feedstuffs such that grass production would become less intensive. This indirect effect from reduced demand for protein rich grass is the main reason why mineral fertilizer use would actually decline somewhat in the low protein scenarios.

Increased efficiency has also the effect that, in particular in ruminant feeding, some expensive feedstuffs may be replaced with cheaper ones such that there would be some savings on protein rich feedstuffs. Remember that the CAPRI simulations try to capture not only optimization of feeding practice in the intensive pigs and poultry sectors but also the avoidance of ‘waste’ in some form on cattle farms. For those there would be an increase in management efforts (included under the heading of ‘feed related’ cost) but at the same time there would be some cost savings, provided the change in feeding practice will come about. As current inefficiency is more widespread in the cattle sector, these cost saving effects tend to benefit the cattle sector, whereas intensive livestock farming is already operating closer to the technological limit. These differences change the relative profitability in the livestock sector. For a decline in the protein surplus from 10% to 5% (which may hold for the pig sector in a country) we would apply the same mark-up of feed cost as for a decline from 30% to 15% because the relative cut of the surplus is the same (50%). However the efficiency gain would benefit the cattle sector. As a consequence we see in many countries a small increase of beef production and as the same time a decline in pork production. Correspondingly EU prices of beef are slightly decreasing (-2.0% in LNF10 all) while pork prices are increasing (+4.7%).

Total excretion is evidently decreasing in the LNF scenarios which makes the largest contribution to the improvement in the nitrogen balance (-830 ktons or -7% in LNF10 all for EU27) but the above mentioned decline in mineral fertiliser use adds another 210 ktons. Total ammonia emissions are expected to decline by 7% whereas leaching is declining by 12% under LNF10 all. The latter effect on leaching is larger than according to MITERRA-EUROPE, among other reasons because mineral fertilizer is slightly increasing on aggregate in MITERRA-EUROPE (+1%) whereas it is somewhat decreasing in CAPRI (-2% on aggregate). Some differences also stem from the definition of leaching in the tables which does not include the runoff parts in CAPRI which are included in Miterra-Europe[2].

The regional differences among countries in the LNF scenarios are first of all due to the different initial protein and energy surplus situations as estimated in the CAPRI database (see Figure 13) because these determine the relative cut factors applied to each animal. However changes in activity level may modify these ‘first round’ effects. In the case of the Czech Republic we see from Figure 13 that for some activities there will not be any surplus at all and thus not a cut in protein supply (which does not hold for the cattle sector). If excretion is increasing here, this is because producers benefit from the price increases without suffering from large cost increases such that they will tend to increase production. In other cases some decline in production contributes to the reduction in excretions in particular if both beef and pork production would decline (Spain, Portugal). The exceptional decline in mineral fertilizer use in Ireland is due to the importance of grassland in this country. The 13% decline under ‘LNF10 all’ in Cyprus is probably also attributable to a peculiar data situation.

2 Runoff is included in CAPRI but it is not aggregated with leaching below the rooting zone.

Table 33: Simulation results of low nitrogen feeding (LNF 10% 2020, all farms) vs. ND full 2020

Absolute change LNF10 all vs. ND full 2020

	agric income [m €]	'net' dir cost [m €]	beef prod [kton]	pork prod [kton]	mineral fertiliser [kton N]	excretion [kton N]	total NH3 loss [kton N]	total CH4 emisions [kton N]	total N2O emisions [kton N]	leaching [kton N]
EU27	-6425	6267	72	-450	-208	-827	-203	53	-35	-120
Austria	-61	115	2	5	0	-16	-4	2	-1	-1
Belgium	-124	205	-3	9	-2	-17	-3	-3	-1	-4
Bulgaria	-65	41	-1	0	-5	-7	-2	0	0	-1
Cyprus	-24	17	0	-5	0	-3	-1	-1	0	0
Czech. Rep	-70	45	3	-2	-6	0	0	3	0	-1
Denmark	-116	68	1	-125	2	-29	-7	-2	-1	-5
Estonia	-8	6	0	0	0	-1	0	0	0	0
Finland	-98	88	-2	-2	0	-5	-1	-2	0	0
France	-976	965	-8	7	-6	-111	-25	-1	-4	-14
Germany	-880	832	2	-213	-11	-113	-34	-3	-4	-15
Greece	-196	173	2	0	-12	-14	-3	1	-1	-1
Hungary	-154	130	-1	-22	-3	-10	-3	0	0	-1
Ireland	-578	606	56	-18	-70	-22	-7	38	-3	-9
Italy	-714	667	4	-10	6	-103	-28	-17	-4	-10
Latvia	-3	4	0	0	-5	-1	-1	1	0	-1
Lithuania	-35	17	0	0	-3	-5	-1	0	0	-2
Malta	-2	3	0	0	0	0	0	0	0	0
Netherlands	-147	261	1	-17	-2	-31	-6	0	-1	-6
Poland	-378	272	0	-15	-8	-48	-16	-5	-2	-6
Portugal	-152	145	-2	-7	-1	-24	-6	-2	-1	-2
Romania	-339	177	6	2	-2	-8	-2	3	0	-1
Slovakia	-11	10	0	-1	-1	-3	-1	0	0	-1
Slovenia	-14	20	-1	1	0	-4	-1	0	0	0
Spain	-842	842	-9	-33	-25	-157	-30	-5	-6	-18
Sweden	-80	114	4	4	6	-11	-3	4	0	0
United Kingdom	-358	443	19	-8	-62	-85	-19	40	-5	-22

Percentage change LNF10 all vs. ND full 2020

	agric income [%]	'net' dir cost [%]	beef prod [%]	pork prod [%]	mineral fertiliser [%]	excretion [%]	total NH3 loss [%]	total CH4 emisions [%]	total N2O emisions [%]	leaching [%]
EU27	-3.2	5.2	0.8	-1.9	-2.0	-8.0	-6.8	0.5	-4.8	-11.6
Austria	-2.0	5.0	1.3	1.0	0.2	-7.4	-7.0	1.0	-4.4	-12.7
Belgium	-3.5	6.1	-1.1	0.8	-1.7	-5.3	-4.4	-1.0	-4.1	-7.2
Bulgaria	-2.5	4.2	-1.0	0.0	-2.5	-5.1	-4.2	-0.1	-3.2	-8.0
Cyprus	-6.1	8.9	-1.8	-27.3	5.6	-13.0	-14.4	-3.0	-8.7	-10.0
Czech. Rep	-4.0	2.8	6.1	-0.4	-1.7	0.1	-0.6	3.7	-1.0	-2.9
Denmark	-3.6	1.7	0.6	-6.5	1.2	-8.3	-8.2	-1.3	-5.3	-11.5
Estonia	-4.0	3.7	-0.8	-0.6	-0.5	-7.4	-6.3	-0.7	-4.0	-7.4
Finland	-7.5	4.1	-2.3	-1.2	0.4	-6.9	-6.0	-2.2	-3.0	-8.1
France	-2.9	4.2	-0.4	0.3	-0.3	-6.8	-4.9	-0.1	-3.1	-7.9
Germany	-4.9	4.2	0.1	-4.6	-0.6	-7.8	-7.0	-0.2	-4.0	-12.5
Greece	-1.9	9.6	3.3	-0.4	-6.2	-8.7	-8.4	0.8	-6.2	-13.1
Hungary	-4.0	4.5	-1.6	-2.7	-0.7	-5.6	-4.3	-0.5	-2.2	-4.8
Ireland	-21.9	19.7	8.5	-6.6	-26.6	-4.2	-6.1	6.7	-9.1	-32.2
Italy	-1.9	5.7	0.4	-0.6	0.8	-11.5	-8.1	-2.0	-6.5	-13.4
Latvia	-1.2	1.9	-2.0	0.9	-9.6	-5.0	-7.0	5.5	-6.6	-21.2
Lithuania	-5.3	2.5	0.6	-0.4	-2.8	-7.9	-6.2	-0.3	-3.4	-14.4
Malta	-2.8	11.8	-2.6	-3.2	0.0	-9.7	-9.2	-1.4	-11.1	-5.3
Netherlands	-1.4	3.8	0.4	-1.3	-1.0	-7.0	-6.8	0.1	-5.5	-8.4
Poland	-4.4	6.0	-0.2	-0.8	-0.8	-8.4	-6.2	-1.2	-3.4	-7.3
Portugal	-3.8	4.8	-1.7	-1.9	-0.9	-11.9	-10.7	-0.9	-8.1	-14.5
Romania	-6.0	4.4	2.2	1.1	-0.3	-2.9	-1.8	1.0	-1.2	-2.3
Slovakia	-1.6	1.3	0.9	-0.4	-0.8	-6.8	-5.3	0.9	-2.5	-7.0
Slovenia	-2.5	6.0	-2.6	4.8	-2.0	-7.9	-6.6	0.4	-5.8	-16.6
Spain	-2.1	7.4	-1.0	-0.9	-3.2	-11.5	-9.5	-0.4	-8.3	-17.6
Sweden	-5.3	5.1	2.6	1.8	3.5	-7.5	-7.4	3.0	-2.7	-1.6
United Kingdom	-3.6	4.4	2.9	-1.4	-7.7	-8.2	-8.8	3.5	-6.6	-18.1

Figure 17 shows the regional distribution of income effects against the ND full reference. It is evident that agriculture rarely gains from the LNF scenario. Exceptions are possible if countries are little affected by increasing feed and management cost but benefit from the general price increase on meat markets.

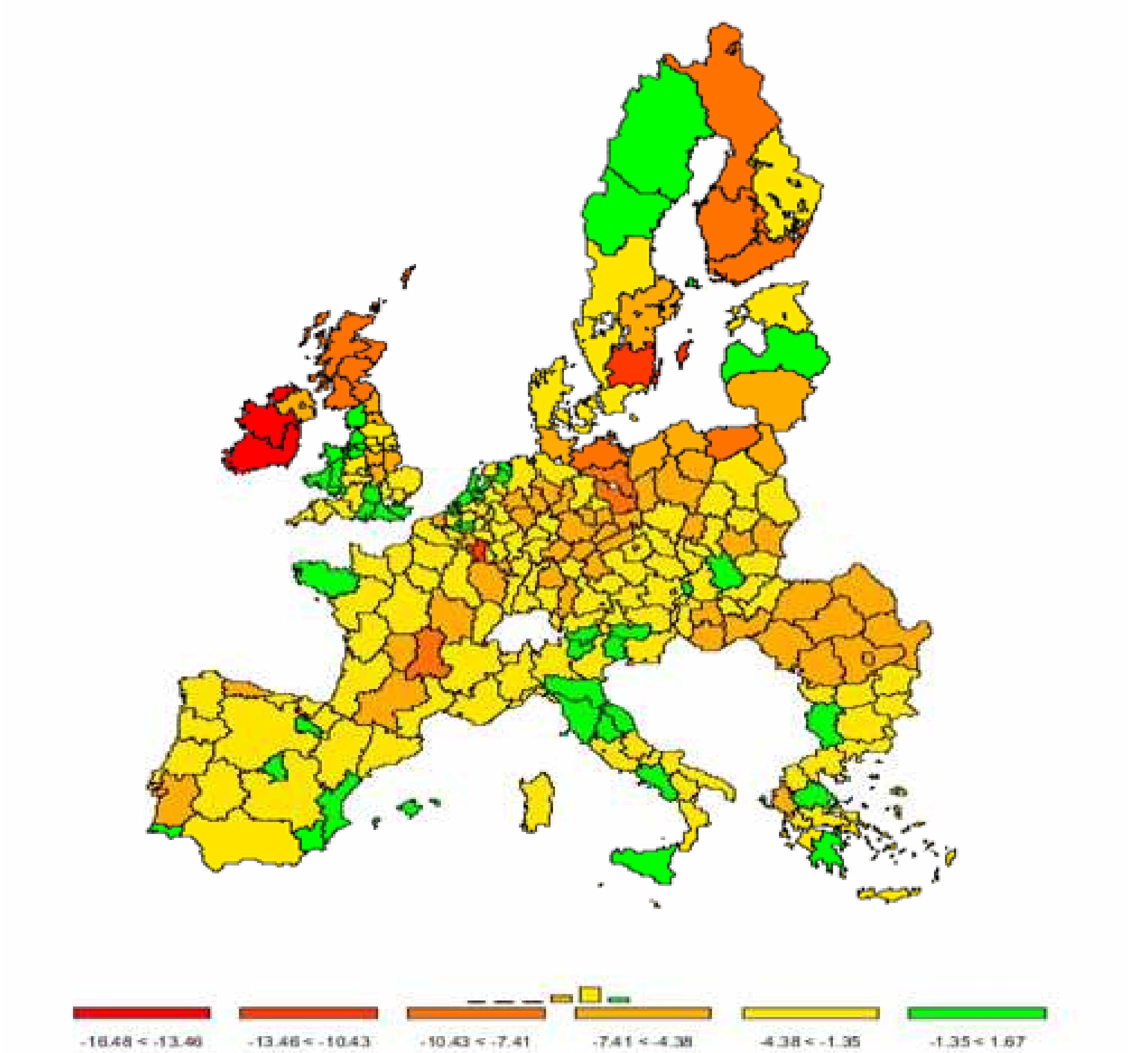

Figure 17. Regional variation of percentage income effects for scenario LNF10, all farms, relative to ND full 2020. (Bars illustrate the distribution)

Table 34 gives the changes of main components of agricultural income from scenario LNF10.

Table 34: Contributions to agricultural income according to CAPRI simulations for the low nitrogen reduction target of 10% in all farms (LNF10, all) vs. ND full 2020

	EAA value [million €]	Unit value EAA [€ / t]	Quantity [1000 t]	EAA value [million €]	Unit value EAA [€ / t]	Quantity [1000 t]
European Union 27						
Production value	426383			-0.2%		
Cereals	35863	106	339507	-6.6%	-6.0%	-0.7%
Other non fodder	157162	252	624354	0.1%	-0.3%	0.4%
Fodder	18944	9	2144968	-1.9%	0.6%	-2.4%
Meat	74266	1616	45947	1.4%	2.6%	-1.2%
Other Animal products	59045	271	217684	2.1%	2.0%	0.1%
Other output	81103	164	494052	-0.9%	0.3%	-1.1%
Inputs	261324			2.1%		
Fertiliser	39283	819	47951	-1.1%	0.0%	-1.1%
Feedingstuff	72481	47	1545314	-7.5%	-6.2%	-1.4%
Other input	149560	281	532491	7.6%	6.9%	0.6%
European Union 15						
Production value	370370			-0.2%		
Cereals	26627	111	240085	-6.1%	-5.6%	-0.6%
Other non fodder	140660	263	534942	0.1%	-0.2%	0.3%
Fodder	15813	9	1767083	-1.8%	0.7%	-2.5%
Meat	64587	1682	38401	1.3%	2.6%	-1.3%
Other Animal products	50905	276	184382	2.2%	2.1%	0.1%
Other output	71777	173	413886	-1.0%	0.2%	-1.2%
Inputs	224756			2.1%		
Fertiliser	31818	850	37423	-1.1%	0.1%	-1.2%
Feedingstuff	63094	48	1325855	-7.5%	-6.1%	-1.5%
Other input	129845	289	448615	7.5%	6.8%	0.7%
European Union 12						
Production value	56013			-0.6%		
Cereals	9236	93	99422	-8.1%	-7.1%	-1.0%
Other non fodder	16502	185	89412	0.4%	-0.5%	0.9%
Fodder	3131	8	377885	-2.2%	-0.1%	-2.1%
Meat	9679	1283	7546	2.4%	2.9%	-0.5%
Other Animal products	8140	244	33302	1.4%	1.5%	-0.1%
Other output	9326	116	80166	0.5%	1.3%	-0.8%
Inputs	36567			2.1%		
Fertiliser	7465	709	10528	-0.8%	0.0%	-0.8%
Feedingstuff	9387	43	219458	-7.7%	-6.9%	-0.8%
Other input	19715	235	83876	7.9%	7.2%	0.6%

The LNF scenarios have stronger market impacts because feed demand would be reduced, at least in terms of quantities. As a consequence cereal prices decline by about 6% which contributes to the loss in agricultural income. On the input side we see a decline in the demand for feedingstuff which implies some savings in cost. However, feed quality and quality of management has to increase which is covered under ‘other input’ giving on balance an increase in costs to agriculture.

The change in agricultural income is one component of the total change in 'economic welfare' (Table 35)

Table 35: Contributions to the change in conventional economic welfare according to CAPRI simulations for the low nitrogen reduction target of 10% in all farms (LNF10) vs. ND full 2020 [million €]

	EU27	EU15	EU12
Total	-11505	-9899	-1606
Consumer money metric	-2841	-2507	-334
Agricultural income	-6425	-5323	-1103
Premiums	8	-2	10
Agricultural Output	-968	-620	-348
Output crops	-2576	-1835	-741
Output animals	1608	1215	393
Output rest	0	0	0
Agricultural Input	5465	4701	765
Crop specific Input	-426	-359	-67
Animal specific Input	-6080	-5434	-646
Other Input	11971	10493	1478
'Net' direct cost	6267	5526	741
Profit of dairies	36	31	5
Profit of other processing	-1974	-1813	-161
Tariff revenues	56	59	-3
FEOGA first pillar	356	346	10

In this scenario significant market impacts have to be expected as mentioned above. In addition to the impacts on agriculture there is a loss in consumer welfare. Furthermore the processing industry, in particular for processing of oilseeds would also be affected by decreasing prices for protein rich feedstuffs. Impacts on the budget are moderate and mainly derive from additional export subsidies on cereals and meat. As under the BALFERT scenario we have to note that the budget impacts do not include estimates for additional advisory efforts and at the same time do not of the public advisory system such that the above welfare cost are underestimated to some extent. However, note also that the benefits of this and other scenarios in terms of reduced emissions have not been monetised. Due to significant impacts on consumers and the processing industry the overall welfare effects considerably exceed the 'net' direct cost of low nitrogen feeding. In the case of low nitrogen feeding these costs are mainly for higher quality of feed and management but net of some savings in quantities and also mineral fertiliser.

Moving to the partial implementation of LNF for IPPC farms only (with extended coverage according to '*IPPC2 2020*' in section 5 of the main report) we find much weaker impacts in general but basically a quite similar picture in qualitative terms (Table 36).

Table 36: Simulation results of low nitrogen feeding (LNF 10% 2020, IPPC farms) vs. ND full 2020

Absolute change LNF10 IPPC2 vs. ND full 2020

	agric income [m €]	'net' dir cost [m €]	beef prod [kton]	pork prod [kton]	mineral fertiliser [kton N]	excretion [kton N]	total NH3 loss [kton N]	total CH4 emisions [kton N]	total N2O emisions [kton N]	leaching [kton N]
EU27	-397	1196	17	-88	-27	-106	-35	16	-6	-15
Austria	26	9	0	2	-1	0	0	0	0	0
Belgium	-4	37	0	0	0	-1	0	0	0	0
Bulgaria	7	-3	0	1	-1	0	0	0	0	0
Cyprus	-3	3	0	-2	0	-1	0	0	0	0
Czech. Rep	-10	20	1	0	-2	0	0	1	0	-1
Denmark	-5	16	0	-26	0	-6	-1	0	0	-1
Estonia	-2	2	0	0	0	-1	0	0	0	0
Finland	4	12	0	2	0	0	0	0	0	0
France	51	129	3	7	-4	-2	-1	3	0	-1
Germany	-56	197	3	-18	-2	-17	-5	1	-1	-2
Greece	-1	14	0	0	-1	0	0	0	0	0
Hungary	-38	53	0	-9	0	-4	-1	0	0	0
Ireland	-42	51	4	-9	-5	1	0	4	0	0
Italy	-124	176	-1	-23	0	-19	-7	-1	-1	-2
Latvia	0	1	0	0	0	0	0	0	0	0
Lithuania	-2	3	0	0	0	-1	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	0
Netherlands	-10	47	0	-1	0	-6	-1	0	0	-1
Poland	-8	48	0	4	-1	-6	-2	0	0	-1
Portugal	-15	29	0	2	0	-2	-1	0	0	0
Romania	9	2	1	2	-1	1	0	1	0	0
Slovakia	-2	5	0	0	0	-2	-1	0	0	0
Slovenia	4	2	0	0	0	0	0	0	0	0
Spain	-118	205	1	-21	-4	-22	-7	1	-1	-2
Sweden	2	16	0	1	1	-1	0	0	0	0
United Kingdom	-61	121	3	0	-6	-17	-6	5	-1	-3

Percentage change LNF10 IPPC2 vs. ND full 2020

	agric income [%]	'net' dir cost [%]	beef prod [%]	pork prod [%]	mineral fertiliser [%]	excretion [%]	total NH3 loss [%]	total CH4 emisions [%]	total N2O emisions [%]	leaching [%]
EU27	-0.2	1.0	0.2	-0.4	-0.3	-1.0	-1.2	0.2	-0.8	-1.4
Austria	0.8	0.4	0.2	0.5	-0.9	0.1	0.1	0.2	-0.1	-0.4
Belgium	-0.1	1.1	0.1	0.0	-0.3	-0.3	-0.3	0.0	-0.4	-0.5
Bulgaria	0.3	-0.3	0.2	0.2	-0.4	0.2	0.1	0.1	-0.1	-0.2
Cyprus	-0.8	1.5	-0.1	-9.2	1.0	-2.9	-4.5	-0.5	-2.2	-1.8
Czech. Rep	-0.6	1.3	2.2	0.1	-0.7	-0.4	-0.5	1.4	-0.5	-1.7
Denmark	-0.2	0.4	0.3	-1.3	0.2	-1.7	-1.8	-0.2	-1.3	-2.3
Estonia	-1.0	1.3	0.0	-0.4	0.0	-3.0	-2.6	-0.2	-2.0	-2.6
Finland	0.3	0.5	0.3	0.8	-0.1	-0.2	-0.2	0.0	-0.2	-0.5
France	0.2	0.6	0.2	0.3	-0.2	-0.1	-0.2	0.1	-0.2	-0.3
Germany	-0.3	1.0	0.3	-0.4	-0.1	-1.2	-1.1	0.1	-0.8	-1.9
Greece	0.0	0.8	0.0	-0.2	-0.3	-0.1	-0.3	0.1	-0.2	-0.4
Hungary	-1.0	1.8	-0.3	-1.0	0.0	-2.4	-1.8	-0.3	-0.8	-1.7
Ireland	-1.6	1.6	0.7	-3.2	-1.8	0.1	-0.3	0.7	-0.4	-1.3
Italy	-0.3	1.5	-0.1	-1.4	0.0	-2.2	-1.9	-0.1	-1.4	-2.4
Latvia	-0.1	0.6	-0.4	0.1	-0.6	-0.9	-0.9	0.2	-0.5	-1.7
Lithuania	-0.3	0.5	0.4	-0.4	-0.2	-0.9	-0.8	0.0	-0.4	-1.3
Malta	0.3	1.3	-0.9	-1.4	0.0	-0.4	0.0	0.0	0.0	0.0
Netherlands	-0.1	0.7	0.1	-0.1	0.2	-1.3	-1.4	0.0	-1.6	-1.3
Poland	-0.1	1.1	0.0	0.2	-0.1	-1.0	-0.7	-0.1	-0.5	-0.9
Portugal	-0.4	1.0	0.0	0.5	-0.4	-1.1	-1.4	0.2	-1.1	-1.4
Romania	0.2	0.0	0.3	0.9	-0.2	0.3	0.2	0.2	0.0	-0.1
Slovakia	-0.2	0.7	0.2	-0.3	0.0	-4.4	-3.2	0.1	-1.6	-3.9
Slovenia	0.6	0.6	-0.3	0.8	-0.4	0.1	0.3	0.0	0.0	0.0
Spain	-0.3	1.8	0.1	-0.6	-0.5	-1.6	-2.2	0.1	-1.6	-2.0
Sweden	0.1	0.7	0.3	0.5	0.5	-1.0	-1.0	0.2	-0.7	0.0
United Kingdom	-0.6	1.2	0.4	0.0	-0.7	-1.6	-3.0	0.4	-1.5	-2.1

Figure 18 shows the regional distribution of income effects against the ND full reference. It is evident that the income losses to agriculture are much smaller if the application is limited to IPPC farms only. Note that regional heterogeneity within Member States is not due to different shares of IPPC farms on which we do not have information. It is mainly driven by differences in production structure and possibly differences in the estimated initial protein surplus.

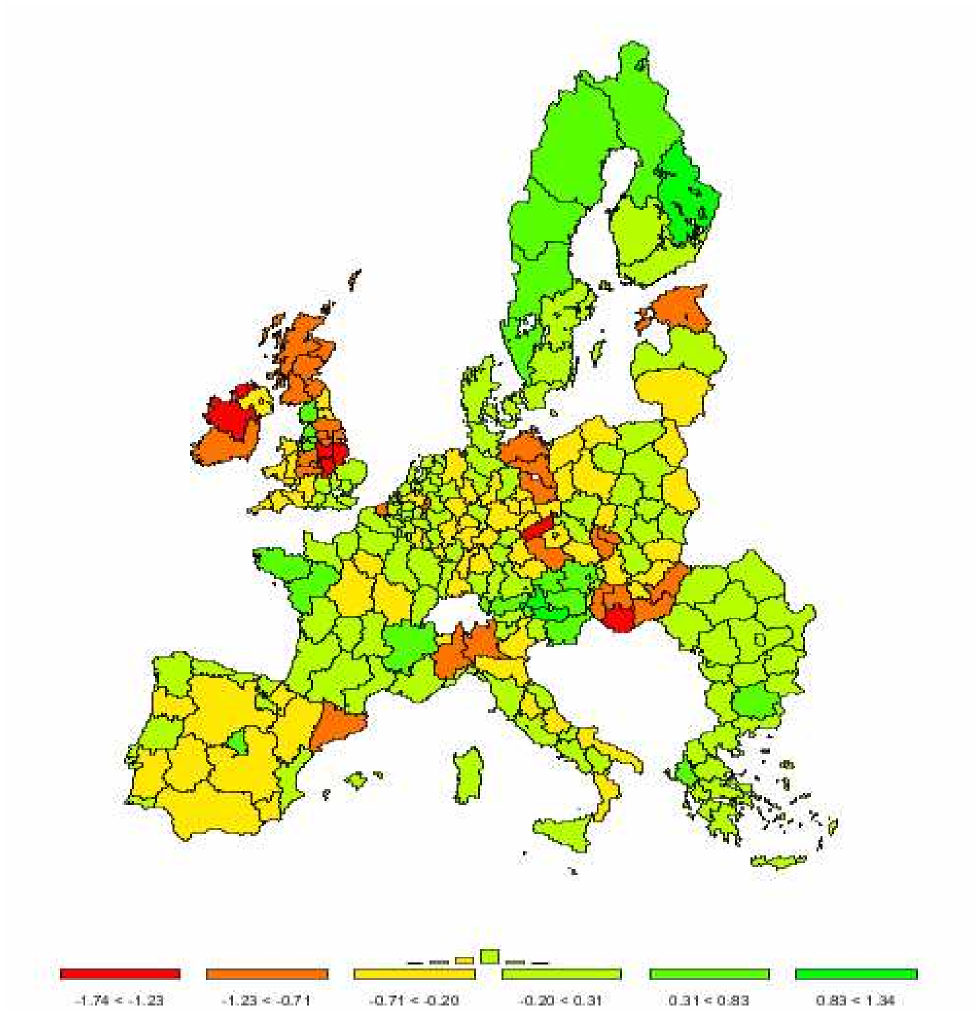

Figure 18. Regional variation of percentage income effects for scenario LNF10 IPPC farms only, relative to ND full 2020. (Bars illustrate the distribution)

Table 37 gives the changes of main components of agricultural income from scenario LNF10, IPPC farms only.

Table 37: Contributions to agricultural income according to CAPRI simulations for the low nitrogen reduction target of 10% in IPPC farms (LNF10 IPPC) vs. ND full 2020

	EAA value [million €]	Unit value EAA [€ / t]	Quantity [1000 t]	EAA value [million €]	Unit value EAA [€ / t]	Quantity [1000 t]
European Union 27						
Production value	426383			0.2%		
Cereals	35863	106	339507	-1.0%	-0.8%	-0.1%
Other non fodder	157162	252	624354	0.1%	0.0%	0.1%
Fodder	18944	9	2144968	-0.2%	0.1%	-0.2%
Meat	74266	1616	45947	0.6%	0.9%	-0.3%
Other Animal products	59045	271	217684	0.9%	0.9%	0.0%
Other output	81103	164	494052	-0.1%	0.1%	-0.2%
Inputs	261324			0.4%		
Fertiliser	39283	819	47951	-0.1%	0.0%	-0.1%
Feedingstuff	72481	47	1545314	-1.1%	-1.0%	-0.1%
Other input	149560	281	532491	1.3%	1.2%	0.1%
European Union 15						
Production value	370370			0.2%		
Cereals	26627	111	240085	-1.0%	-0.8%	-0.1%
Other non fodder	140660	263	534942	0.1%	0.0%	0.1%
Fodder	15813	9	1767083	-0.2%	0.1%	-0.2%
Meat	64587	1682	38401	0.6%	1.0%	-0.4%
Other Animal products	50905	276	184382	0.9%	0.9%	0.0%
Other output	71777	173	413886	-0.1%	0.1%	-0.2%
Inputs	224756			0.4%		
Fertiliser	31818	850	37423	-0.1%	0.0%	-0.1%
Feedingstuff	63094	48	1325855	-1.1%	-1.0%	-0.2%
Other input	129845	289	448615	1.3%	1.2%	0.1%
European Union 12						
Production value	56013			0.2%		
Cereals	9236	93	99422	-0.9%	-0.8%	-0.2%
Other non fodder	16502	185	89412	0.2%	0.1%	0.1%
Fodder	3131	8	377885	-0.3%	0.0%	-0.2%
Meat	9679	1283	7546	1.1%	1.0%	0.1%
Other Animal products	8140	244	33302	0.5%	0.5%	0.0%
Other output	9326	116	80166	0.1%	0.1%	0.0%
Inputs	36567			0.4%		
Fertiliser	7465	709	10528	-0.1%	0.0%	-0.1%
Feedingstuff	9387	43	219458	-1.1%	-1.1%	-0.1%
Other input	19715	235	83876	1.3%	1.1%	0.2%

The LNF scenario has weaker market impacts if it is limited to IPPC farms. Meat prices are only expected to increase by 1% rather than 2.7 % under 'LNF10 all' and cereal prices would only drop by 0.8% rather than 6% in EU27. On the input side we see the counteracting changes for feedingstuff and 'other input' which incorporates the 'quality mark up'.

The change in agricultural income is one component of the total change in 'economic welfare' (Table 38)

Table 38: Contributions to the change in conventional economic welfare according to CAPRI simulations for the low nitrogen reduction target of 10% in IPPC farms (LNF10) vs. ND full 2020 [million €]

	EU27	EU15	EU12
Total	-2437	-2160	-277
Consumer money metric	-1450	-1271	-179
Agricultural income	-397	-352	-45
Premiums	16	15	1
Agricultural Output	696	597	99
Output crops	-210	-156	-54
Output animals	906	752	154
Output rest	0	0	0
Agricultural Input	1109	964	145
Crop specific Input	-42	-36	-6
Animal specific Input	-894	-796	-98
Other Input	2045	1796	249
'Net' direct cost	1196	1059	137
Profit of dairies	14	12	2
Profit of other processing	-541	-494	-46
Tariff revenues	13	22	-8
FEOGA first pillar	77	76	1

In this scenario market impacts are weaker than under LNF10 (all) as mentioned above. Nonetheless there is a loss in consumer welfare and a loss in the processing industry. Impacts on the budget are quite small, disregarding expenditure for additional advisory efforts. The 'net' direct cost capture only apart of the total economic cost of the measure as changes market prices pass on the loss to other market participants and enforce economic adjustments involving welfare cost. Nonetheless even the 'net' direct cost give already a more encompassing cost indicator than agricultural income effects alone.

With a further implementation of LNF towards a 20% target many effects discussed earlier would be strengthened of course. However, there are also new aspects. In this scenario all meat prices would increase (12% for beef, 18% for pork) such that there would be a significant burden to final consumers. A large part of the additional cost of the measures would thus be passed on to consumers. Whereas the economic impacts of this scenario are important this evidently holds as well for the environmental gains (Table 39).

It will be recognized that the impacts on excretion and hence all derived environmental effects are stronger in these CAPRI simulations than in the MITERRA-EUROPE results from above. This is mainly because the CAPRI simulations tend to cover the efficiency gains in the non dairy cattle and sheep sectors as well but some adjustments of activity levels also contribute to the differences.

Table 39: Simulation results of low nitrogen feeding (LNF 20% 2020, all farms) vs. ND full 2020

Absolute change LNF20 all vs. ND full 2020

	agric income [m €]	'net' dir cost [m €]	beef prod [kton]	pork prod [kton]	mineral fertiliser [kton N]	excretion [kton N]	total NH3 loss [kton N]	total CH4 emisions [kton N]	total N2O emisions [kton N]	leaching [kton N]
EU27	-8962	17788	-113	-1274	-330	-1909	-436	-368	-80	-250
Austria	-81	368	2	-8	3	-39	-9	-6	-1	-1
Belgium	-379	759	-17	-59	-1	-39	-8	-7	-1	-7
Bulgaria	-75	117	-4	5	-8	-13	-3	-1	-1	-3
Cyprus	-43	50	0	-7	1	-5	-1	-1	0	0
Czech. Rep	-83	120	8	5	-12	2	0	7	0	-2
Denmark	-105	259	-14	-380	5	-55	-13	-9	-2	-9
Estonia	-9	17	0	0	0	-2	-1	0	0	0
Finland	-297	326	-12	-10	3	-14	-3	-8	0	0
France	-1279	3079	-145	-51	5	-257	-55	-83	-9	-30
Germany	-1159	2641	-86	-374	-14	-235	-68	-53	-8	-29
Greece	-644	285	31	0	-1	-49	-5	-27	-2	-2
Hungary	-270	348	0	-53	-7	-18	-6	0	-1	-2
Ireland	-61	554	188	-34	-107	-145	-29	-28	-8	-22
Italy	-1602	2245	-1	-136	7	-231	-64	-77	-8	-21
Latvia	4	12	-1	1	-9	-3	-1	2	0	-2
Lithuania	-39	48	2	1	-10	-7	-2	2	-1	-3
Malta	-2	5	0	-1	0	0	0	0	0	0
Netherlands	-315	901	-37	-69	2	-72	-14	-6	-3	-12
Poland	-554	715	6	-9	-18	-78	-27	-6	-4	-11
Portugal	-235	380	-5	-12	-5	-70	-16	-38	-3	-4
Romania	-552	412	12	12	-5	-12	-3	7	-1	-2
Slovakia	7	33	1	2	-2	-5	-1	0	0	-1
Slovenia	-19	59	-4	4	0	-7	-2	-1	0	-1
Spain	-1344	3006	-77	-107	-29	-309	-60	-30	-11	-32
Sweden	-114	324	5	29	15	-24	-6	0	-1	0
United Kingdom	290	725	32	-23	-144	-221	-41	-7	-13	-53

Percentage change LNF20 all vs. ND full 2020

	agric income [%]	'net' dir cost [%]	beef prod [%]	pork prod [%]	mineral fertiliser [%]	excretion [%]	total NH3 loss [%]	total CH4 emisions [%]	total N2O emisions [%]	leaching [%]
EU27	-4.4	14.7	-1.3	-5.5	-3.2	-18.6	-14.6	-3.6	-10.8	-24.1
Austria	-2.7	15.9	1.1	-1.7	3.3	-18.2	-16.2	-2.7	-11.2	-21.9
Belgium	-10.8	22.5	-5.5	-5.2	-1.0	-12.1	-11.3	-2.5	-8.9	-15.0
Bulgaria	-2.8	11.9	-2.7	1.2	-3.9	-9.1	-7.3	-0.3	-5.4	-13.8
Cyprus	-11.2	26.5	-2.5	-44.2	11.3	-23.4	-25.7	-6.0	-16.3	-17.2
Czech. Rep	-4.8	7.5	16.3	1.2	-3.6	1.7	-0.4	7.3	-1.5	-5.3
Denmark	-3.3	6.5	-11.5	-19.9	3.0	-15.9	-15.7	-4.8	-9.8	-21.3
Estonia	-4.5	10.5	2.0	0.6	-1.2	-13.2	-11.2	-1.7	-6.6	-13.5
Finland	-22.8	15.2	-15.6	-5.2	2.6	-17.6	-15.5	-9.5	-7.7	-15.7
France	-3.9	13.6	-7.7	-1.9	0.3	-15.8	-11.0	-3.9	-7.0	-17.2
Germany	-6.5	13.2	-7.4	-8.0	-0.8	-16.3	-13.8	-4.5	-8.2	-24.2
Greece	-6.1	15.9	55.6	0.1	-0.5	-31.3	-16.7	-14.9	-14.8	-29.1
Hungary	-7.0	11.9	1.2	-6.5	-1.6	-10.2	-8.2	-0.5	-4.2	-9.0
Ireland	-2.3	18.0	28.5	-12.1	-40.8	-28.0	-25.5	-4.9	-29.9	-77.1
Italy	-4.3	19.2	-0.1	-8.0	1.0	-25.6	-18.5	-8.9	-14.8	-27.5
Latvia	1.6	5.2	-3.8	5.8	-18.1	-10.5	-13.3	8.2	-12.9	-41.6
Lithuania	-5.9	7.4	6.6	1.2	-8.9	-10.6	-10.2	3.4	-7.1	-30.7
Malta	-2.7	23.0	-3.4	-23.6	3.9	-21.2	-19.7	-5.9	-22.2	-15.8
Netherlands	-3.0	13.1	-11.1	-5.3	1.2	-16.4	-16.0	-1.7	-12.9	-17.4
Poland	-6.5	15.8	3.1	-0.5	-1.8	-13.9	-10.5	-1.5	-5.8	-13.0
Portugal	-5.9	12.5	-3.7	-3.3	-5.0	-34.2	-29.4	-16.8	-25.4	-36.2
Romania	-9.8	10.3	4.3	5.4	-1.1	-4.7	-3.0	2.2	-2.3	-5.0
Slovakia	1.1	4.5	6.7	1.6	-1.9	-11.4	-8.7	0.9	-4.3	-12.4
Slovenia	-3.4	17.9	-13.0	11.9	-1.4	-16.0	-12.9	-2.5	-11.1	-30.6
Spain	-3.3	26.4	-8.0	-3.0	-3.8	-22.5	-18.7	-2.3	-15.8	-31.6
Sweden	-7.5	14.5	3.5	12.7	9.3	-17.1	-15.3	0.2	-6.6	-5.5
United Kingdom	2.9	7.1	4.8	-4.2	-17.9	-21.3	-18.7	-0.7	-16.6	-43.2

Figure 19 shows the regional distribution of income effects against the ND full reference. There is a great regional heterogeneity, partly due to different productions structure and initial protein surplus. The relatively high loss in Finland is mainly a basis effect: Compared to many other countries Finish agriculture is not very profitable, for example measures in terms of agricultural income relative to total revenue (about 30%). A certain squeeze from additional cost may cause a large relative drop in income when starting from a low level.

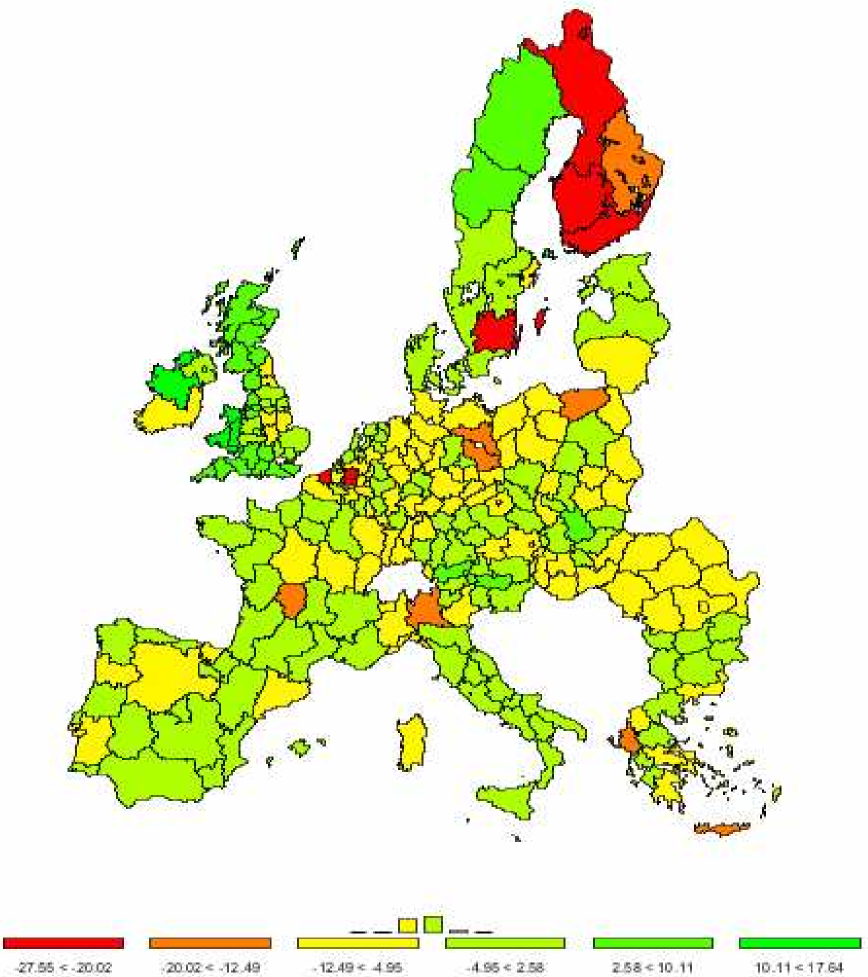

Figure 19. Regional variation of percentage income effects for scenario LNF20 all relative to ND full 2020.

Table 40 gives the changes of main components of agricultural income from scenario LNF20.

Table 40: Contributions to agricultural income according to CAPRI simulations for the low nitrogen reduction target of 20% in all farms (LNF20) vs. ND full 2020

	EAA value [million €]	Unit value EAA [€ / t]	Quantity [1000 t]	EAA value [million €]	Unit value EAA [€ / t]	Quantity [1000 t]
European Union 27						
Production value	426383			4.9%		
Cereals	35863	106	339507	-13.0%	-12.6%	-0.5%
Other non fodder	157162	252	624354	0.5%	-0.4%	0.8%
Fodder	18944	9	2144968	-5.7%	2.5%	-8.0%
Meat	74266	1616	45947	10.8%	15.9%	-4.4%
Other Animal products	59045	271	217684	8.6%	9.2%	-0.6%
Other output	81103	164	494052	15.8%	23.7%	-6.4%
Inputs	261324			11.4%		
Fertiliser	39283	819	47951	-3.2%	0.1%	-3.3%
Feedingstuff	72481	47	1545314	-15.4%	-9.6%	-6.4%
Other input	149560	281	532491	28.3%	30.3%	-1.6%
European Union 15						
Production value	370370			5.5%		
Cereals	26627	111	240085	-11.7%	-12.0%	0.3%
Other non fodder	140660	263	534942	0.3%	-0.2%	0.5%
Fodder	15813	9	1767083	-5.9%	3.1%	-8.8%
Meat	64587	1682	38401	10.7%	17.0%	-5.4%
Other Animal products	50905	276	184382	8.9%	9.7%	-0.7%
Other output	71777	173	413886	17.5%	27.1%	-7.5%
Inputs	224756			12.3%		
Fertiliser	31818	850	37423	-3.5%	0.2%	-3.7%
Feedingstuff	63094	48	1325855	-15.7%	-9.1%	-7.3%
Other input	129845	289	448615	29.8%	32.9%	-2.3%
European Union 12						
Production value	56013			0.9%		
Cereals	9236	93	99422	-16.6%	-14.7%	-2.2%
Other non fodder	16502	185	89412	1.8%	-0.7%	2.6%
Fodder	3131	8	377885	-4.7%	-0.2%	-4.5%
Meat	9679	1283	7546	11.6%	10.8%	0.7%
Other Animal products	8140	244	33302	6.4%	6.4%	0.0%
Other output	9326	116	80166	2.7%	3.4%	-0.7%
Inputs	36567			5.9%		
Fertiliser	7465	709	10528	-1.8%	0.0%	-1.7%
Feedingstuff	9387	43	219458	-13.5%	-12.4%	-1.3%
Other input	19715	235	83876	18.1%	15.5%	2.3%

The LNF20 scenario has even stronger market impacts than LNF10. Especially meat production decreases clearly (-4.6%). Price increases from animal products compensate for the decrease in quantity such that the total production value is increasing. Price effects on cereals are strong as well. On the input side we see a marked decline in the demand for feedingstuff which implies again some savings in cost. However, feed quality and quality of management has to increase which is covered under ‘other input’ giving on balance a sizeable increase in costs to agriculture (+11.4%).

The change in agricultural income is one component of the total change in 'economic welfare' (Table 41)

Table 41: Contributions to the change in conventional economic welfare according to CAPRI simulations for the low nitrogen reduction target of 20% in all farms (LNF20) vs. ND full 2020 [million €]

	EU27	EU15	EU12
Total	-31372	-27716	-3656
Consumer money metric	-16966	-15316	-1650
Agricultural income	-8962	-7325	-1637
Premiums	-8	-29	21
Agricultural Output	20883	20370	513
Output crops	-5015	-3640	-1375
Output animals	25898	24011	1888
Output rest	0	0	0
Agricultural Input	29837	27667	2171
Crop specific Input	-1189	-1055	-134
Animal specific Input	1996	2959	-963
Other Input	29030	25763	3268
'Net' direct cost	17788	15852	1937
Profit of dairies	239	213	27
Profit of other processing	-5716	-5256	-460
Tariff revenues	566	482	84
FEOGA first pillar	535	514	21

Welfare effects from LNF20 would be clearly stronger than from LNF10. Agricultural income has further decreased but consumers losses have increased more than fivefold. Together with a stronger loss on other processing (due to less feed demand of oilcakes) this would lead to a tripled reduction in conventional total welfare compared to LNF10. The two caveats from above, ignorance of additional administrative cost and lack of monetised environmental benefits apply as usual. Finally it may be seen again that 'net' direct costs as a simpler indicator of economic costs fail to capture the full size of welfare cost but are nonetheless more inclusive than agricultural income effects.

The most ambitious package analysed by our models combines balanced fertilization, low nitrogen feeding (10% target for all farms) and the ammonia measures considered for the Thematic Strategy (**Optimal combination**). Excretion would decline by 8% according to CAPRI but the key contribution would come from a decline of mineral fertilizer by 13% which is even larger than under balanced fertilization alone because the effect of lower protein demand on grass production is added on top (Table 42). Reduced nitrogen supply combines with targeted ammonia measures to reduce ammonia emissions by 19%. Leaching would also be alleviated significantly by -26% (where the difference to the lower leaching impact according to MITERRA-Europe is partly due to the exclusion of runoff from the leaching result in CAPRI). Finally we have to repeat our caveat on the data situation in Malta and Cyprus which contributed to exaggerated effects on mineral fertilizer in these countries.

Table 42: Simulation results of a combined low nitrogen feeding, balanced fertilization and ammonia measures from TS explorations (optimal combination) vs. ND full 2020

	agric income [m €]	'net' dir cost [m €]	beef prod [kton]	pork prod [kton]	mineral fertiliser [kton N]	excretion [kton N]	total NH3 loss [kton N]	total CH4 emisions [kton N]	total N2O emisions [kton N]	leaching [kton N]
EU27	-10831	11446	27	-535	-1295	-862	-558	17	-19	-266
Austria	-147	196	1	-3	-9	-17	-16	1	1	-1
Belgium	-94	230	-3	19	-28	-16	-6	-2	-1	-10
Bulgaria	-200	184	-1	1	-45	-7	-3	0	-1	-10
Cyprus	-27	13	0	-7	-7	-3	-1	-1	0	-1
Czech. Rep	-181	161	0	-3	-48	-1	-5	2	-1	-12
Denmark	-334	218	0	-214	-8	-35	-26	-4	0	-4
Estonia	-35	34	0	0	-2	-1	-1	0	0	0
Finland	-121	114	-2	-1	-1	-5	-3	-2	0	0
France	-1533	1658	-11	-4	-196	-116	-121	-6	5	-39
Germany	-964	1078	-17	-170	-19	-115	-44	-11	-3	-15
Greece	-474	410	1	-10	-35	-17	-11	0	0	-3
Hungary	-288	277	-1	-18	-45	-10	-12	-1	0	-8
Ireland	-869	899	43	-25	-81	-31	-16	28	-2	-10
Italy	-1132	1205	2	-13	-116	-105	-72	-19	-3	-25
Latvia	-58	57	0	-1	-11	-2	-2	1	0	-2
Lithuania	-67	50	0	-1	-6	-6	-5	-1	0	-2
Malta	-1	3	0	0	0	0	0	0	0	0
Netherlands	-135	314	1	0	-5	-30	-9	0	-1	-6
Poland	-899	861	-2	-14	-161	-48	-42	-7	-3	-30
Portugal	-301	303	-3	-10	-31	-26	-16	-4	0	-4
Romania	-857	705	6	4	-49	-8	-4	3	-1	-11
Slovakia	-41	46	0	-1	-8	-3	-2	0	0	-2
Slovenia	-59	54	-3	0	-3	-6	-7	-2	0	0
Spain	-1446	1548	-7	-69	-256	-159	-94	-3	-3	-42
Sweden	-113	165	4	7	-8	-10	-3	4	-1	-1
United Kingdom	-456	663	20	0	-121	-83	-37	41	-4	-30

Percentage change Opt combination vs. ND full 2020

	agric income [%]	'net' dir cost [%]	beef prod [%]	pork prod [%]	mineral fertiliser [%]	excretion [%]	total NH3 loss [%]	total CH4 emisions [%]	total N2O emisions [%]	leaching [%]
EU27	-5.3	53.2	0.3	-2.3	-12.5	-8.4	-18.6	0.2	-2.6	-25.6
Austria	-4.8	29.1	0.7	-0.6	-10.1	-8.0	-28.5	0.6	7.4	-11.0
Belgium	-2.7	99.6	-1.1	1.7	-22.2	-5.0	-8.5	-0.8	-3.4	-20.4
Bulgaria	-7.5	107.8	-1.0	0.2	-22.3	-5.1	-8.5	-0.1	-10.5	-57.0
Cyprus	-7.0	142.8	-3.1	-44.6	-88.4	-16.2	-36.9	-4.9	-21.7	-55.2
Czech. Rep	-10.4	43.3	1.0	-0.7	-14.3	-1.1	-11.3	2.1	-5.4	-38.9
Denmark	-10.5	53.9	-0.3	-11.2	-4.4	-10.1	-32.0	-2.2	0.8	-9.9
Estonia	-16.5	141.7	-0.9	-0.8	-7.7	-7.3	-14.2	-0.4	-2.6	-14.4
Finland	-9.3	20.0	-2.1	-0.4	-1.0	-6.7	-13.9	-1.9	3.9	-7.6
France	-4.6	45.1	-0.6	-0.2	-9.2	-7.1	-24.3	-0.3	4.0	-22.1
Germany	-5.4	38.0	-1.4	-3.6	-1.1	-8.0	-9.1	-0.9	-3.2	-12.4
Greece	-4.5	233.9	2.1	-8.5	-18.5	-10.6	-32.3	-0.2	-4.3	-31.9
Hungary	-7.5	45.8	-2.9	-2.2	-10.2	-5.7	-17.3	-0.7	-0.5	-28.6
Ireland	-32.9	116.4	6.6	-9.0	-30.8	-5.9	-14.5	5.0	-7.8	-34.9
Italy	-3.0	60.0	0.2	-0.7	-15.7	-11.6	-20.8	-2.3	-5.4	-32.3
Latvia	-22.4	96.4	-2.1	-4.3	-22.6	-5.8	-23.2	5.1	-5.8	-43.1
Lithuania	-10.2	47.0	-0.7	-1.3	-5.3	-9.3	-20.8	-1.8	0.1	-14.7
Malta	-1.5	84.6	-1.7	-1.1	-51.0	-9.3	-9.2	-0.9	-11.1	-26.3
Netherlands	-1.3	17.9	0.2	0.0	-2.5	-6.8	-9.7	0.0	-3.7	-8.1
Poland	-10.5	389.6	-1.1	-0.7	-16.2	-8.5	-16.2	-1.6	-5.3	-36.0
Portugal	-7.5	43.0	-2.3	-2.7	-29.9	-12.9	-30.8	-1.9	-2.7	-39.9
Romania	-15.3	60.5	2.2	1.7	-10.2	-2.9	-5.0	1.0	-4.6	-28.7
Slovakia	-6.0	24.8	1.6	-0.5	-7.0	-6.6	-12.6	1.1	-2.9	-20.4
Slovenia	-10.4	98.2	-10.6	-0.9	-15.6	-12.6	-40.4	-4.3	12.1	-14.0
Spain	-3.6	182.7	-0.8	-1.9	-33.0	-11.6	-29.4	-0.3	-4.4	-41.5
Sweden	-7.4	22.9	2.6	2.9	-4.7	-7.3	-8.7	3.1	-5.0	-24.7
United Kingdom	-4.6	29.6	2.9	0.0	-15.0	-8.0	-17.0	3.6	-5.2	-24.3

Figure 20 shows the regional distribution of income effects against the ND full reference. It is evident that the income effects are quite negative for most regions.

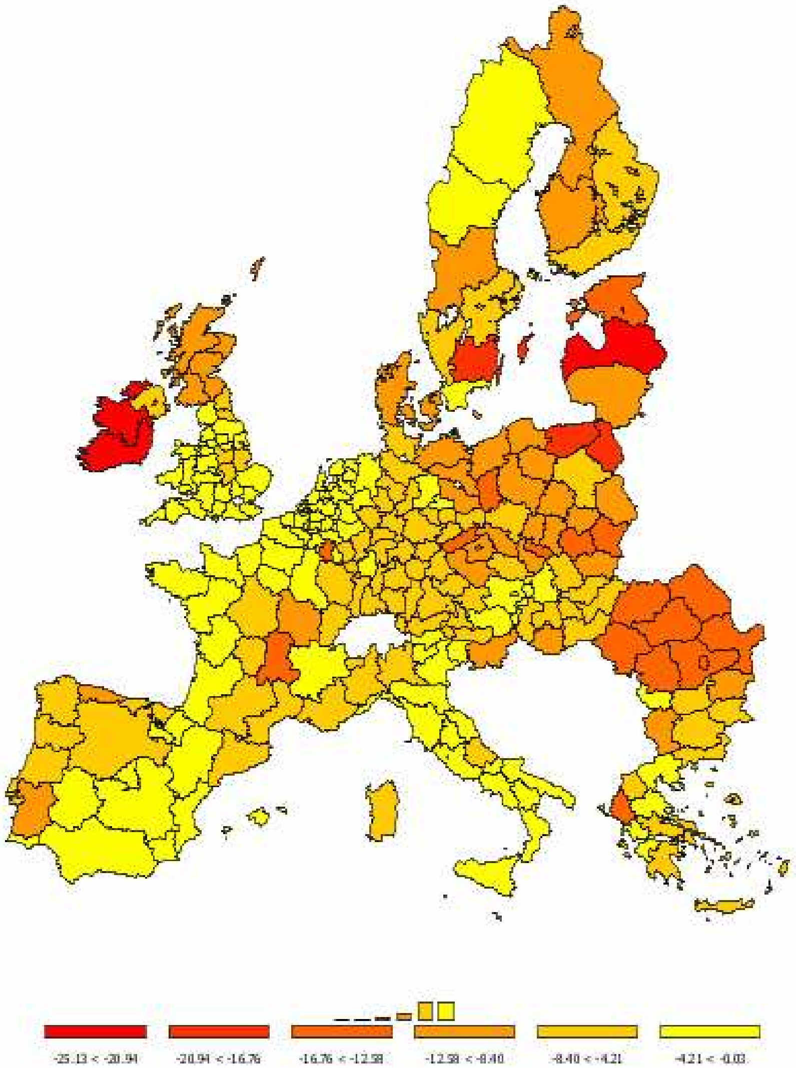

Figure 20. Regional variation of percentage income effects for scenario 'Optimal combination' relative to ND full 2020. (Bars illustrate the distribution)

Table 43 gives the changes of main components of agricultural income from the scenario 'Optimal combination'.

Table 43: Contributions to agricultural income according to CAPRI simulations for combined low nitrogen feeding, balanced fertilization and ammonia measures from TS explorations (optimal combination) vs. ND full 2020

	EAA value [million €]	Unit value EAA [€ / t]	Quantity [1000 t]	EAA value [million €]	Unit value EAA [€ / t]	Quantity [1000 t]
European Union 27						
Production value	426383			0.1%		
Cereals	35863	106	339507	-6.8%	-6.0%	-0.8%
Other non fodder	157162	252	624354	0.1%	-0.2%	0.4%
Fodder	18944	9	2144968	-1.9%	0.6%	-2.5%
Meat	74266	1616	45947	2.4%	4.0%	-1.5%
Other Animal products	59045	271	217684	2.1%	2.1%	0.0%
Other output	81103	164	494052	0.1%	1.7%	-1.5%
Inputs	261324			4.3%		
Fertiliser	39283	819	47951	-2.8%	0.0%	-2.9%
Feedingstuff	72481	47	1545314	-8.0%	-6.5%	-1.5%
Other input	149560	281	532491	12.2%	11.0%	1.1%
European Union 15						
Production value	370370			0.2%		
Cereals	26627	111	240085	-6.3%	-5.8%	-0.5%
Other non fodder	140660	263	534942	0.1%	-0.2%	0.3%
Fodder	15813	9	1767083	-1.8%	0.7%	-2.5%
Meat	64587	1682	38401	2.3%	4.1%	-1.7%
Other Animal products	50905	276	184382	2.2%	2.2%	0.0%
Other output	71777	173	413886	0.0%	1.7%	-1.6%
Inputs	224756			3.9%		
Fertiliser	31818	850	37423	-2.6%	0.0%	-2.6%
Feedingstuff	63094	48	1325855	-8.0%	-6.4%	-1.7%
Other input	129845	289	448615	11.3%	10.3%	0.9%
European Union 12						
Production value	56013			-0.4%		
Cereals	9236	93	99422	-8.3%	-6.8%	-1.6%
Other non fodder	16502	185	89412	0.5%	-0.3%	0.8%
Fodder	3131	8	377885	-2.2%	-0.1%	-2.1%
Meat	9679	1283	7546	3.0%	3.7%	-0.6%
Other Animal products	8140	244	33302	1.4%	1.6%	-0.3%
Other output	9326	116	80166	1.1%	2.1%	-0.9%
Inputs	36567			6.8%		
Fertiliser	7465	709	10528	-3.8%	-0.1%	-3.7%
Feedingstuff	9387	43	219458	-7.9%	-7.1%	-0.9%
Other input	19715	235	83876	17.8%	15.5%	2.0%

The market impacts are in part an overlay of the impacts from scenarios LNF10 (all farms) and BALFERT, but the ammonia measures contribute to the additional cost in the livestock sector and tend to reduce supply and increase prices. Meat prices are therefore increasing by 4.1% rather than 2.7 % under 'LNF10 all' but the drop in cereal prices is very similar to the LNF10 scenario. On the input side we may observe a decline in expenditure on fertiliser and feedstuffs which is more than compensated by the additional costs for 'other input'.

The change in agricultural income is one component of the total change in 'economic welfare' (Table 44).

Table 44: Contributions to the change in conventional economic welfare according to CAPRI simulations for combined low N feeding, balanced fertilization and ammonia measures from TS explorations (optimal combination) vs. ND full 2020 [million €]

	EU27	EU15	EU12
Total	-16959	-13589	-3370
Consumer money metric	-3954	-3485	-469
Agricultural income	-10831	-8119	-2713
Premiums	-2	-24	21
Agricultural Output	536	783	-247
Output crops	-2600	-1843	-757
Output animals	3136	2625	510
Output rest	0	0	0
Agricultural Input	11365	8878	2487
Crop specific Input	-1120	-828	-292
Animal specific Input	-5835	-5179	-656
Other Input	18320	14885	3436
'Net' direct cost	11446	9001	2445
Profit of dairies	37	32	5
Profit of other processing	-1993	-1816	-177
Tariff revenues	69	64	4
FEOGA first pillar	288	267	21

In this scenario market impacts would be most significant of course. There is a loss in consumer welfare and a sizeable loss to the processing industry, in particular for processing of oilseeds. Impacts on the budget are moderate. The two caveats from above, ignorance of additional administrative cost and lack of monetised environmental benefits apply as usual. As market impacts are smaller than under the LNF20 scenario (Table 41) the 'net' direct cost better reflects total welfare cost than above.

The key results from the CAPRI simulations are summarized in Table 45

Table 45: Simulation results of low nitrogen feeding, balanced fertilization and 'optimal combination' measures vs. ND full 2020 in EU27

	agric income [m €]	consumer welfare [m €]	total econ welfare [m €]	total NH3 loss [kton]	total CH4 emisions [kton N]	total N2O emisions [kton N]	leaching [kton N]
BALFERT	-3058	-26	-3056	-53	-1	-19	-157
LNF10 all	-6425	-2841	-11505	-203	53	-35	-120
LNF10 IPPC	-397	-1450	-2437	-35	16	-6	-15
LNF20 all	-8962	-16966	-31372	-436	-368	-80	-250
Opt combination	-10831	-3954	-16959	-558	17	40	-266
				abatement relative to welfare cost estimate			
				NH3 [g / €]	CH4 [g / €]	N2O [g / €]	leaching [g / €]
BALFERT				17	0	6	51
LNF10 all				18	-5	3	10
LNF10 IPPC				14	-7	2	6
LNF20 all				14	12	3	8
Opt combination				33	-1	-2	16

With all caveats due to the significant uncertainties it appears that balanced fertilization achieves significant improvements on leaching at moderate cost whereas progress on ammonia emissions would be quite moderate.

Low nitrogen feeding is less efficient in terms of reduced leaching but it is an important ingredient of an overall strategy if sizable ammonia abatement is to be achieved. It is evident that a great part of the economic loss is born by consumers. Price increases of 10% and more have been projected under the ambitious variant of low nitrogen feeding and the size of these price increases is part of the uncertainties. Among other influences they hinge on the unknown degree of consumer preferences for EU produced meat which determine the amount of pass through of additional cost in the livestock sector. With greater substitutability the economic losses would fall more on agriculture than on consumers. When comparing the moderate (10%) goal with the more ambitious objective of a 20% reduction the simulation results conform to intuition: Achieving a more ambitious target involves a more than proportionate increase in cost.

The optimal combination is shown to yield significant contributions at economic cost between those of the BALFERT and LNF scenarios for leaching and at lowest cost for ammonia. Apparently the mix of ammonia targeting measures selected for the RAINS simulations was quite efficient in economic terms. This should be the case as economic efficiency was guiding the selection procedure for the RAINS model.

The economic costs do not encompass estimates of the additional administrative cost in EU and national administrations and advisory services. On the other hand the term total welfare cost should not be read as implying that the overall economic balance is negative: As we have not tried to put monetary values on the abatements achieved it is possible and even likely that the overall balance would be positive. There economic welfare cost indicated are meant in a quite narrow sense therefore and refer only to the conventional welfare components.

9. Discussion and conclusions

Implementation of low-protein animal feeding has multiple beneficial environmental effects. Our analyses indicates that a decrease of 10% in the protein content of the animal feed on all farms will lower the NH_3 emissions by 6% and the N leaching and emissions of N_2O by 4% relative to the ND full 2020 reference scenario. This indicates that low-protein animal feeding has synergistic effects. Decreasing the protein content of the animal feed by 20% would further decrease the NH_3 emissions by 11% and the N leaching and emissions of N_2O by 6% relative to the ND full 2020 reference scenario. Hence, the effects of the decreases in protein content are suggested to be linear.

Balanced N fertilization also has multiple beneficial environmental effects. Full implementation of balanced fertilization in this study (removing 'over-fertilization') was equivalent to decreasing the N input via N fertilizer by on average 9% and that via animal manure by up to 6%, relative to the ND full 2020 reference scenario. Balanced fertilization (Balfert 2020) decreases the NH_3 emissions by 4%, N leaching by 11% and the emissions of N_2O by 4% relative to the ND full 2020 reference scenario. However, balanced fertilization as applied in this study is not without cost for the farmer. It may increase the risk of a decrease in crop yield. Furthermore, areas with high livestock density may be forced to lower the N content of the animal manure through low-protein animal feeding or may have to treat the manure, to be able to implement balanced fertilization and to utilize the nutrients in the animal manure efficiently. The balanced N fertilization measure has considerable perspectives for decreasing the N loading of the environment, but when applied too strict it can have considerable agronomic and economic effects as well. Further sensitivity analyses are needed.

Combined implementation of an optimal set of NH_3 emission abatement measures (RAINS optimized 2020) and balanced fertilization ('Optimal Combination 2020') has also 'far-reaching' effects. It decreases the NH_3 emission by 19% relative to the ND full 2020 reference scenario to a level of ~ 2420 kton NH_3 from agriculture in EU-27. This level is slightly below the target levels (~ 2450 kton for EU-25 and ~2650 kton for EU-27; Aman et al., 2006b) needed to achieve the objectives of the Thematic Strategy on Air Pollution in 2020. In addition, the Optimal Combination 2020 scenario decreases mean N leaching by 14% and mean N_2O emissions by 3% relative to the ND full 2020 reference scenario. However, the Optimal Combination 2020 scenario is not without cost for the farmer. The annual cost of the NH_3 emission abatement measures have been estimated at € 1.6 billion for the EU-25, in addition to the cost already associated with current legislation. Further, relatively large amounts of manure N have to be 'neutralized' through a combination of low-protein animal feeding and manure treatment in some regions, at considerable additional costs.

The results of the MITERRA-EUROPE and CAPRI simulations agree rather well. Though the activity data are based on similar sources, the modelling concepts are different. CAPRI is an economic optimization model, while MITERRA-EUROPE largely is an empirical factor model. Both models arrive at the conclusion that the identified most promising measures can contribute greatly to the decrease in the emissions of NH_3 and N_2O to the air and the leaching of N to groundwater and surface waters. However, these benefits are not without costs. The differences between the MITERRA-EUROPE and CAPRI simulations can be seen as a contribution to sensitivity analyses.

The scope for lowering the total N excretion of animals in the EU-27 by 10 to 20% is based on the following combination of measures:

- lowering the protein content of animal feed, with or without additions of specific amino acids and improved phase feeding;
- improvement of the genetic potential of the herds, i.e., increasing the milk yield per cow and the growth rate of pigs, poultry and beef animals; and
- lowering the replacement rate of dairy cattle, increasing the growth rate of young dairy stock and lowering the age of the young stock at first calving.

Considerable investments in demonstration, training farmers and research are needed to be able to achieve an overall lowering of the protein content of the animal feed by on average 10-20%. The genetic improvements mentioned above would have to be on top of the baseline increase in productivity. As it is unclear whether such improvements will come about it may be questioned whether the 20% decrease is technically feasible on the majority of farms.

In this study, it is assumed that lowering the N excretion by 10% through low-protein animal feeding decreases the NH_3 emissions proportionally (i.e., by 10%). However, there is a considerable amount of empirical and theoretical evidence that lowering of the N excretion by 10% through low-protein animal feeding decreases the NH_3 emissions more than proportionally (Kulling et al., 2001; 2003; Broderick, 2003; Flachowsky and Lebzien, 2005; Jondreville and Dourmad, 2005; Mateos et al., 2005; Misselbrook et al., 2005; Velthof et al., 2005). In addition, the metabolizable energy and the cation composition of the diets affect the pH of the urine and the animal manure and thereby the NH_3 emissions too. This suggests that more precise animal diet prescriptions and more precise model formulation for assessing the effects of diet composition on NH_3 emissions are needed, to be able to fully capture the variance in practice in the relationships between animal feed composition, manure composition and NH_3 emissions.

In addition to diet composition, high-technological measures, such as the use of antibiotics, antimicrobial agents, and certain growth hormones could be used to lower NH_3 emissions, but these measures are not considered here, because of animal welfare reason (these measures do not satisfy the criterion of ‘most promising’).

The available data do not allow to making a more precise estimate of the potential for decreasing the N excretion by animals in the EU-25+, than the suggested rough mean of 10-20%. The accuracy of the estimated potential decrease in N excretion is on the one hand constrained by our limited knowledge of the animal physiology and especially the animal nutrition (the minimum requirement for amino acids), and on the other hand by our limited knowledge of current practice. The current information in RAINS indicates that (i) there is little variation in practice as regards the mean N excretion of dairy cattle, other cattle, pigs and poultry among countries, and (ii) that the N excretion of these main livestock categories in the various countries is not (excessively) high. Hence, on the basis of the RAINS database, there is only limited scope for decreasing N excretion. In practice, there appears to be a large variation between farms in the N excretions of for example dairy cattle, pigs and poultry, suggesting room for lowering N excretion on at least some farms (e.g., Hubeek and De Hoop, 2004). This variation between farms is averaged out in the Member States means, and it is not always clear how the Member States arrived at these means. The RAINS data also indicate that there is very limited scope for regional differentiation in the scope for decreasing N excretion (but there is scope for regional differentiation in the level of implementation .

The suggested decrease of the N excretion by animals by roughly 10-20% in the next 10 to 15 years will be achieved only with proper incentives, including

- training and advising farmers;
- demonstration trials and demonstration farms;
- covenants with animal feed industry and farmers;
- research for improving the requirement of animals for amino acids and the diagnosis of amino acids in diets.

The Nitrates Directive exerts a strong implicit incentive to lower the N excretion rate of livestock through its Code of Good Agricultural Practice, which states that the maximum application rate of N via animal manure is 170 kg N per ha per year. This application limit indirectly also limits livestock density and N excretion rate of the livestock (the lower the N excretion per animal, the more animals can be kept per unit agricultural land). Evidently, this incentive is most applicable to countries and regions with a relatively high livestock density.

For making more accurate assessments of the prospects for lowering N excretion through further lowering of the protein content in the animal feed, it is recommended that a thorough survey is being made of the animal feeding practices and animal performances in the EU-27. A uniform methodology must be applied for estimating the regional variation in N excretion by animals. The current N excretion values in RAINS are based on estimates by country specialists, and it is unclear whether these estimates reflect indeed the variation that occurs in practice. This holds as well for the projected number of animals for the next decades. More precise estimates of the regional variation in N excretion will also allow making more accurate estimates of the potential for decreasing N excretion by animals.

Our results indicate that balanced fertilization is a possible most promising measure. There is scope for improving the N use efficiency in crop production by more efficient use of animal manure and fertilizers and hence by a lower fertilizer N input. This holds especially for the intensively managed crop production systems (including forage production) in many EU-15 Member States. Our estimate indicates that N input in EU agriculture can be decreased. Mosier et al (2004) suggested that increases in NUE of about 10-30 relative to present levels appear feasible in many regions, through fine-tuning of the N management. However, strict implementation of balanced fertilization has the risk of lowering crop yield and quality. Because of the risks involved of balanced N fertilization, it would be worthwhile to explore the possibilities of using support to those farmers that go beyond a less strict interpretation of balanced fertilization via the Rural Development Regulation. This has been anticipated already in the CAPRI simulations where the decrease of the overfertilisation factor has been large but less than 100% to acknowledge that farmers may be reluctant to reduce fertiliser input if the decline of yields cannot be avoided anymore through more precise application.

There are various reports from EU Member States indicating that significant improvements have been made (and can be made further) in N use efficiency and in decreasing N surpluses in agriculture through a combination of measures. Denmark is a typical example in this case. The N use efficiency in Danish agriculture has increased steadily during the last 10 to 20 years. The success of the Danish case has been ascribed to two factors, namely (i) mandatory fertilizer and crop rotation plans, with limits on the amount of plant available N to be applied to different crops, and (ii) the statutory norms for the fraction of manure N assumed to be plant available. These two instruments have been enforced stepwise between 1991 and 2004, and have been designed in close dialogue with farmers and farmers associations. The regulations are supported by extensive information materials, demonstration, extension and education. Also, extensive research programs have been supported (Dalgaard, 2006). Rather similar success stories have been reported for the Netherlands (Van Grinsven et al., 2005).

The lessons to be learned from the Danish case and other cases is that a steady lowering of N surpluses and a steady increase of the N use efficiencies can be made only following the implementation of sound policies and measures, including the training of farmers and extension services, and supported by extensive research programs. Mosier et al (2004) state that improvements in NUE require knowledge intensive N management practices and are brought about by:

- increased yields and more vigorous crop growth, associated with greater stress tolerance of modern crop varieties;
- improved management of production factors other than N (tillage, seed quality, plant density, weed and pest control, balanced fertilization of other nutrients than N; and
- improved N fertilizer and animal manure management, to better match the amount and timing of applied N to crop N demand.

Prerequisites for implementing such practices are that they must be simple and user friendly, involve little extra time, provide consistent gains in NUE and yield and are cost-effective. Optimizing the timing, quantity and availability of applied N is the key to achieving a high NUE. They require suitable policies and significant long-term investments in research, extension and education. The policies and investments need to be regional specific, because of the different agricultural practices and priorities in different countries.

There are possible future developments which may hinder a possible decrease in the protein content of the animal feed and in the N fertilizer input in agriculture. This hindrance is related to the development of the use of bio fuels. The increasing demand for biofuels will compete to some extend with the demand for high-quality animal feed, because there is hardly land unused in the world. It has been suggested that an increasing supply of low-quality by-products from the production of biodiesel and ethanol will become available on the market. These by-products (DDGS) of the biofuel industry are poor in energy and rich in protein and fiber (but have low-quality protein), after the energy has been distilled and removed. As a consequence, the protein content of the animal feed may have the tendency to increase again in the near future, when these trends become noticeable. Also, the increasing acreage of biofuels will likely contribute to intensification of agricultural production (on a smaller area, because of the land used for biofuel production). This further intensification of the agricultural production on a smaller area may contribute to increased N emissions per unit of utilized agricultural area, even though the total N emissions from agricultural production may not increase necessarily.

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