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National and regional net nitrogen balances in Finland in 1990–2005

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Nitrogen (N) balance has been identified as a principal agri-environmental indicator. In addition to national N balances, calculation of N balances for different agricultural regions is also recommended. In this study, national and regional net N balances for Finland were calculated. The net N balance is the result of deducting the NH_3-N losses from manure and fertilisers from the gross N balance. The N balance calculation was based on data for Finnish Rural Centres and calculated per cultivated hectare. The main data inputs for the calculations were agricultural and environmental statistics, coefficients of manure excretion and crop N concentrations. Finnish national net N balance decreased from 90 kg ha^{-1} in 1990 to 50 kg ha^{-1} in 2005. The decrease in regional N balances was of the same magnitude. The main reason for the lower N balances was reduced use of mineral N fertilisers. Variation in the N balances was due to yield levels varying according to growing season conditions. The Rural Centres with intensive animal production tended to generate the highest N balances.

Key-words: nitrogen balance, agricultural regions, animal manures, fertiliser, yield

Introduction

Nutrient use in agriculture should be sufficient to maintain crop and forage production, but should generate minimal surpluses that pollute water and air. “The calculation of nitrogen (N) balances has been identified as a priority agri-environmental indicator by OECD Member countries” (OECD/EUROSTAT 2003). The information represented by N balances is needed to analyse the interactions between agriculture and the environment and to evaluate the impact of changes in agricultural policy on the environment.

Several methods are used to measure the inputs and outputs and thereby calculate a nutrient balance. “Soil surface balance” (Parris 1998) or “gross and net nitrogen balance” (OECD/EUROSTAT 2003) are terms for a calculation method that is used by many OECD countries and international organisations. Basically these methods assess the difference between the annual total quantity of N entering the soil and the annual quantity of N leaving the soil. The gross N balance includes all emissions of N compounds from agriculture into the soil, water and air. The

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net N balance excludes N emissions into the air, and the N volatilisation and denitrification from fertiliser and manure should be deducted from the gross N balance (OECD/EUROSTAT 2003).

As national authorities calculate national N balances, there is also a demand for regional N balances because some areas can experience nitrate pollution and some areas depletion of N (Parris 1998). Parris (1998) stated that N balance itself indicates only potential for pollution, not actual pollution and suggested that trends in N balance represent a practical and low cost tool for estimating potential environmental effects.

The purpose of this study was to calculate national and regional net N balances in Finland to estimate the potential for N losses to the environment. The net N balance was calculated by excluding ammonia volatilisation but not denitrification losses, which are difficult to estimate, especially those for N_2. In this study, N balance means net N balance unless otherwise stated. The trends in N balances could also show the influence of the Finnish Agri-Environmental Program started in 1995, although other changes in Finnish agriculture during 1990–2005 have also taken place. An additional objective was to describe available data and methods for N balance calculations. The quality of agricultural data and coefficients are also discussed.

Material and methods

The N balance calculation was based on data from Finnish Rural Centres (Fig. 1). In 1990, there were 20 Rural Centres, of which Nylands svenska lantbrukssällskap was integrated into Uusimaa and Finska Hushållningssällskapet into Farma. During the last three years, 2003–2005, data from Päijät-Häme Rural Centre were not available as they were included with those of Häme Rural Centre. Rural Centres were used instead of other regional districts as N fertiliser data were only available for the Rural Centres. National N balance was calculated on the basis of the regional N balances. The main elements of the N balance calculation and their magnitudes are shown in Table 1.

Data from sales of N fertiliser were obtained from the most important fertiliser suppliers in Finland. Data obtained from Kemira GrowHow Oyj were distributed according to the Rural Centre and sales from other companies were distributed evenly for the entire cultivated area.

The input of manure N from different farm animals was calculated according to manure excretion coefficients (Table 2) used in environmental guidelines for livestock production (Ministry of Environment 1998). The volatilisation of ammonia was calculated according to the coefficients for different farm animals and manure management strategies (Grönroos et al. 1998).

Volatilisation of ammonia from mineral fertilisers was estimated as 0.6% of their N content

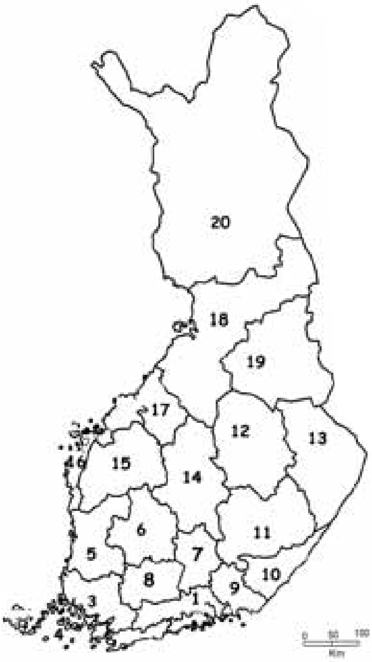

Fig. 1. Location of Rural Centres. Numbers represent the following Rural Centres: 1. Uusimaa, 2. Nylands svenska lantbrukssällskap, 3. Farma, 4. Finska Hushållningssällskapet, 5. Satakunta 6. Pirkanmaa, 7. Päijät-Häme, 8. Häme, 9. Kymenlaakso, 10. Etelä-Karjala, 11. Mikkeli, 12. Pohjois-Savo, 13. Pohjois-Karjala, 14. Keski-Suomi, 15. Etelä-Pohjanmaa, 16. Österbotten, 17. Keski-Pohjanmaa, 18. Oulu, 19. Kainuu, 20. Lappi.

Table 1. The balance sheet for the nitrogen balance calculation.

Balance components	Magnitude in Finland in 1990–2005, kg ha^{-1}
Nitrogen inputs	
+ Fertilisers (mineral and organic)	75–115
+ Livestock manure	42–55
+ Biological nitrogen fixation	3–7
+ Atmospheric deposition	4–6
+ Other inputs (seeds etc.)	2–4
Nitrogen outputs	
– Harvested yield	65–80
The gross nitrogen balance	60–105
– Ammonia volatilisation	
from fertilisers	< 1
from livestock manure	12–16
The net nitrogen balance	46–87

Table 2. Annual nitrogen (N) excretion per animal. Coefficients from the Finnish Ministry of the Environment (1998), OECD Secretariat (1997) and Finnish greenhouse gas emission calculations (averaged 1990–2004, Statistics Finland 2006).

	N excretion, kg yr^{-1}		
	Ministry of the Environment	OECD	Finnish greenhouse gas emission
Cattle < 1 year	27	35	33
Male Cattle 1–2 years	55	46	58
Female Cattle 1–2 years	45	n.a.	45
Male Cattle > 2 years	55	59	58
Heifers > 2 years	45	n.a.	45
Dairy Cows	100	98	94
Other Cows	55	n.a.	61
Pigs < 20 kg	3.3	n.a.	n.a.
Pigs 20 – 50 kg	11	11	n.a.
Fattening Pigs > 50 kg	11	11	18
Boars	11	13	n.a.
Sows	*40	26	n.a.
Sheep	17	11	7
Lambs	17	n.a.	7
Goats	17	14	17
Broilers	0.2	0.3	0.4
Broiler hens	0.8	n.a.	0.9
Layers	0.8	0.7	0.7
Cockerels	0.8	n.a.	1.1
Turkeys	0.6	1.5	1.2
Horses	65	n.a.	58
Foxes (kg per produced pelt)	1.9	n.a.	2.3
Minks (kg per produced pelt)	1.1	n.a.	1.3

* with piglets; n.a. = not available in the reference

(Pipatti et al. 2000). This coefficient is clearly less than the 10% estimate of the IPCC (2002) as fertilisers used in Finland have low volatilisation potential and placement of fertilisers is a standard application method (Pipatti et al. 2000).

Deposition of N was estimated according to the measurements of the Finnish Environment Institute and the Finnish Meteorological Institute (Kuusisto 1997, Leppänen et al. 2000, Vuorenmaa et al. 2001, Vuorenmaa 2005).

The amount of biological N fixation was calculated from the N content of pea (*Pisum sativum* L.) production added to N fixed by clover (*Trifolium* L.) in cultivated grass in organic farming and in seed production. The amount of N fixed by the clover-grass swards was estimated to be 140 kg ha^{-1}. It is an average value from two years measured in clover-grass swards of organic farms in Finland in the southern Savo region (Väisänen 2000). Associative N fixation was estimated to be 4 kg ha^{-1} in cereals rye (*Secale cereale* L.), barley (*Hordeum vulgare* L.) and oats (*Avena sativa* L.) and grasses such as timothy (*Phleum pratense* L.) and meadow fescue (*Festuca pratensis* Huds.).

Other sources of N entering agricultural soils included seeds and sewage sludge used in agriculture. Sewage sludge comes from wastewater treatment plants and is used as an organic fertiliser or soil conditioner after composting. The amount of sewage sludge used in agriculture was obtained from the VAHTI-database, maintained by the Finnish Environment Institute and N concentration came from the literature (Kulmala and Esala 2000). In our calculations, sewage sludge N was evenly distributed over the cultivated area. Nitrogen input from seeds was calculated according to recommended seeding rates for each crop and seed nutrient content came from the literature (Tuori et al. 1996), and cultivated area of each crop was obtained from agricultural statistics (Information Centre of the Ministry of Agriculture and Forestry 1991–2005).

Cultivation areas for the different crops and numbers of different farm animals were obtained directly from the 1990–1991 Yearbook of Farm Statistics (Information Centre of the Ministry of Agriculture and Forestry 1990, 1991) and calculated for the Rural Centres by the Information Centre of the Ministry of Agriculture and Forestry for 1992–2005. Crop yields per hectare were taken from national statistics (Information Centre of the Ministry of Agriculture and Forestry 1992–2006), using the data from representative Employment and Economic Development Centres or Rural Business Districts in 1992–2005, when data from Rural Centres were not available. Nitrogen contents of crops were calculated from protein concentrations taken from the Finnish tables of feeding recommendations (Tuori et al. 1996). Calculations were done for the time period 1990–2005.

To assess the possible trend in N balances and its components in 1990–2005, a simple linear regression model was used.

$$Y = \beta_0 + \beta_1 X + \varepsilon$$

where β_0 is the intercept in the year 1990, β_1 is the effect of one year, X is the year and ε is the random error. For both national and regional N balances, linear regression was calculated for fertiliser and manure N input, yield N output and the N balances. All statistical tests were performed at $p = 0.05$ and a coefficient of determination (R^2) was used to describe the accuracy of the predicted trend.

Results

National N balance

The N input decreased from 160 kg ha^{-1} at the beginning of the 1990s to almost 120 kg ha^{-1} in 2005 (Table 3). The main reason for this is decrease in the use of mineral N fertilisers. The N output in the harvest ranged from 65 to 80 kg ha^{-1}. Variation is mainly attributable to the extent of unfavourable climatic conditions, which changed across growing seasons. The net N balance decreased during the calculated time period from 90 to 50 kg ha^{-1} (Table 3). Gross N balance decreased from 110 kg ha^{-1} to 60 kg ha^{-1}. The difference between gross and net N balance decreased from 17 to 14 kg ha^{-1}. This difference stems mainly from ammonia volatilisation from manure and its decrease is attributable to reduced cattle production. The cultivated agricultural area varied due to set-aside agreements and was lowest in 1991–1994. Thus total gross balance (gross N balance x cultivated area) decreased below the earlier lowest value (in 1993) only after 2000 (Table 3).

The trends in the input of N in mineral fertilisers (–2.2 kg $ha^{-1}yr^{-1}$) and manure (–0.9 kg $ha^{-1}yr^{-1}$) were clear and affected the decrease in both gross N balance (–2.5 kg $ha^{-1}yr^{-1}$) and net N balance (–2.3 kg $ha^{-1}yr^{-1}$, Table 4). Despite the decreased N input, yield N output did not tend to decrease (p=0.156).

Regional N balances

The N surplus of the regional N balances also decreased in all but one Rural Centre during the period of calculation (Table 5). In the Rural Centre of Österbotten, N surplus was fairly constant in the 1990s. On closer inspection the use of N in fertilisers was 20–30 kg ha^{-1} lower than in the other Rural Centres, mainly due to a high percentage of organic soils (25%) in Österbotten. In addition, clay soils are almost absent in the area of Österbotten Rural Centre, and sandy soils are the dominant soil type. Compared with sandy and organic soils, clay soils are associated with 10–20 kg ha^{-1} and 20–40 kg ha^{-1}, respectively, higher N recommendations for cereals in the area (Viljavuuspalvelu 2000).

During the early 1990s N surpluses in the intensive livestock regions were clearly higher than N surpluses in the cereal production regions (Table 5, Fig. 2). These N surpluses were reduced towards 2000. In 1990–2005, the annual decrease in N balance in intensive livestock regions was -2.4 – -3.5 kg $ha^{-1}yr^{-1}$. The decrease was only slightly lower, -1.5 – -2.9 kg $ha^{-1}yr^{-1}$, in regions that concentrate more on cereal production.

Figure 2 shows the main components of N balance from two Rural Centres. Cereal production dominates in Uusimaa and milk production in Pohjois-Savo. Grassland occupies 20% of the cultivated area in Uusimaa and 60% in Pohjois-Savo. As for the Rural Centres in Figure 2, the decrease in N balance in most Rural Centres is based on reduc-

Table 3. Gross and net nitrogen (N) soil surface balances (kg ha^{-1}) in Finland in 1990–2005.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	SD
Nitrogen inputs																	
Mineral fertilisers	113.6	112	92.9	94.3	94.1	101.7	92.8	86.2	84.9	82.7	84.6	85.7	80	79.6	76.7	74.2	11.6
Ammonia emission	–0.7	–0.7	–0.6	–0.6	–0.6	–0.6	–0.6	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5	–0.5	–0.4	0.1
Manure	51.1	54.8	55.1	53.9	53.6	49.7	50.1	50.1	47.7	46.8	44.9	43.8	42.7	43.5	42.1	42.1	4.7
Ammonia emission	–14.5	–15.5	–15.6	–15.2	–15.2	–13.9	–14.1	–14.2	–13.5	–13.2	–12.6	–12.3	–12	–12.3	–11.9	–11.9	1.3
Seeds	3.1	2.9	2.7	2.7	2.7	2.6	2.8	2.9	2.9	3.0	3.0	3.0	3.0	3.2	3.4	3.4	0.2
N deposition	5.6	5.4	5.7	3.6	4.1	4.5	4.4	4.4	4.4	4.2	4.4	4.4	4.4	4.4	4.4	4.4	0.6
Biological N fixation	2.9	3.5	3.6	3.8	4.0	4.0	4.0	4.5	5.4	5.9	6.5	6.4	6.4	7.0	7.3	7.3	1.5
Sewage sludge	0.9	0.7	0.6	0.6	0.9	0.6	0.7	0.8	0.3	0.2	0.3	0.4	0.3	0.4	0.2	0.2	0.3
Net input	162.0	163.1	144.4	143.1	143.6	148.6	140.1	134.2	131.6	129.1	130.6	130.9	124.3	125.3	121.7	119.3	13.2
Harvested	78.6	76.6	69.3	80.3	75.5	77.2	77.5	75.9	65.2	67.2	79.8	73.0	73.5	70.9	71.7	73.2	4.4
Net balance	83.4	86.5	75.1	62.8	68.1	71.4	62.6	58.3	66.4	61.9	50.8	57.9	50.8	54.4	50.0	46.2	11.8
Gross balance	98.6	102.7	91.3	78.6	83.9	85.9	77.3	73.0	80.4	75.6	63.9	70.7	63.3	67.2	62.4	58.5	13.0
Cultivated area (1000 ha)	2050	1808	1758	1784	1797	1922	1936	1964	2000	1965	2006	1990	1969	1992	2023	1993	93.9
Total gross balance on the cultivated area (1000 t)	202	186	161	140	151	165	150	143	161	149	128	141	125	134	126	117	22.7

Table 4. Linear regression equations for the national nitrogen (N) balances and their components (kg ha^{-1}).

Component or balance	Equation	Probability	R^2
Mineral fertiliser N	109 – 2.2X	<0.001	0.83
Manure N	56 – 0.9X	<0.001	0.89
Yield N	77 – 0.3X	0.156	0.14
Net N balance	82 – 2.3X	<0.001	0.83
Gross N balance	99 – 2.5X	<0.001	0.86

tion of both mineral fertiliser and manure N input. Only in the Rural Centres of Österbotten and Lappi was the N input in mineral fertiliser not clearly decreased. Manure N input and animal densities did not decrease in Farma + Finska Hushållningssällskapet and Österbotten Rural Centres.

Local weather conditions cause variation in N surpluses among the Rural Centres. For example, high N surpluses in Uusimaa and Farma in 1999 were caused by low rainfall during the growing season. Cereal yields are usually more vulnerable to unfavourable weather conditions than grass yields, as can be seen from the yield N variation in Uusimaa and Pohjois-Savo Rural Centres (Fig. 2). In 1990–2005, there were three Rural Centres (Pirkanmaa, Etelä-Pohjanmaa and Oulu) where a decreasing trend explains approximately 30% of yield N reduction. The effect of 0.6–0.8 kg ha^{-1} a^{-1} can partially be related to the substitution of grassland with cereals.

Discussion

N balance surplus

The decrease in net N balance from 90 kg ha^{-1} to 50 kg ha^{-1} implies more efficient use of N in agriculture and should result in reduced N leach-

Table 5. Regional soil surface net nitrogen (N) balances (kg ha^{-1}).

Rural Centre	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	SD
Uusimaa + NSL[1]	77	80	88	62	55	70	57	48	60	79	42	52	54	51	46	42	14
Farma + FHS[2]	95	92	96	66	73	84	71	65	80	87	67	68	71	70	58	54	13
Satakunta	78	82	66	54	61	73	60	51	68	52	51	60	57	55	39	47	12
Pirkanmaa	73	72	56	56	64	60	48	48	54	51	39	45	41	43	44	33	11
Häme	82	84	75	69	75	91	65	62	70	76	56	54	55	48	45	37	15
Päijät-Häme	72	70	70	48	66	66	51	54	56	60	39	39	40	n.a.	n.a.	n.a.	12
Kymenlaakso	75	79	97	70	68	75	66	60	60	72	44	50	43	47	41	46	16
Etelä-Karjala	75	87	82	63	81	76	68	71	55	72	49	54	51	54	53	50	13
Mikkeli	82	93	67	65	70	70	67	72	65	61	57	46	43	44	50	42	14
Pohjois-Savo	112	117	82	81	89	87	79	74	78	62	67	62	59	63	55	45	19
Pohjois-Karjala	91	108	65	66	67	67	56	58	67	49	52	51	48	47	43	40	18
Keski-Suomi	88	89	71	69	62	56	48	53	64	56	49	53	47	48	49	47	14
Etelä-Pohjanmaa	79	83	65	66	73	67	62	60	76	59	60	63	53	62	56	53	9
Österbotten	55	64	47	53	57	52	58	62	71	47	48	53	50	57	55	53	6
Keski-Pohjanmaa	110	118	84	90	94	94	81	82	89	63	77	76	71	77	69	70	15
Oulu	79	98	75	67	74	67	62	61	59	44	49	54	46	49	59	55	14
Kainuu	124	112	82	74	82	94	79	75	85	59	63	67	53	67	60	55	20
Lappi	86	88	77	55	68	77	66	72	83	65	66	47	45	63	50	57	13
SD	16	16	13	10	10	13	10	10	11	12	11	9	9	10	8	9	

n.a. = not available, N surplus of Päijät-Häme Rural Centre is integrated into Häme Rural Centre for 2003–2005

[1] NSL = Nylands svenska lantbrukssällskap, [2] FHS = Finska Hushållningssällskapet

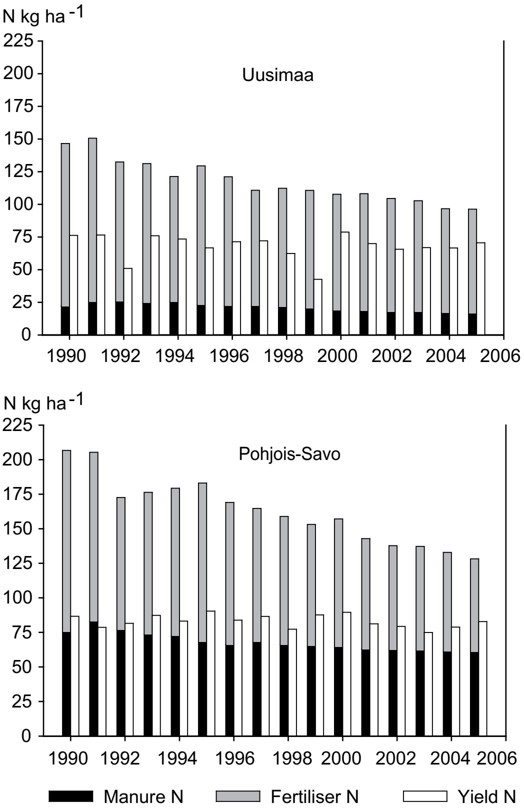

Fig. 2. The main components of nitrogen (N) balance in the Rural Centres of Uusimaa and Pohjois-Savo.

ing. However, as the cultivated area was smaller in 1991–1994, due to set-aside, the total N balance decreased beyond that only after 2000.

This calculation led to a similar N balance as reported by Antikainen et al. (2005) for 1995–1999. There the nitrogen balance of Finnish agricultural soils was 62 kg ha^{-1} between 1995 and 1999, which agrees with the average value of 63 kg ha^{-1} from our calculation for those years. Antikainen et al. (2005) divided the N surplus in soil into leaching of 15 kg ha^{-1} (Vuorenmaa et al. 2002) and denitrification of 18 kg ha^{-1} (Finnish Ministry of the Environment 2002), and thus the remaining N surplus in soil was 29 kg ha^{-1}. Measurements of N leaching provided annual figures of 10–20 kg ha^{-1} (Salo and Turtola 2006), which agree with the estimate of Vuorenmaa et al. (2002). Measurements of nitrous oxide emissions indicated annual losses of 2–8 kg ha^{-1} from mineral soils (Syväsalo et al. 2004) and 4–25 kg ha^{-1} from peat soils (Regina et al. 2004). Regarding nitrous oxide emissions, it is difficult to estimate total denitrification as N_2:N_2O can range from 0.1 to 5.7 (Mathieu et al. 2006).

As organic carbon in Finnish arable soils decreased according to results of a field survey (Mäkelä-Kurtto and Sippola 2002) and a field experiment (Esala and Larpes 1984) by 0.3% in 10 years, it is unlikely that soil organic matter can retain N. This suggests that N leaching, denitrification and volatilisation losses are higher than currently verified by measurements. Because denitrification as N_2 gas is the process for which there are practically no measurements in Finland, it can be considered the most likely loss pathway. While some researchers estimate that denitrification explains 50–90% of N surplus (e.g. Kroeze et al. 2003), others estimate that only about 10% of the soluble N entering the ecosystem might be lost via denitrification (Janzen et al. 2003).

Uncertainty in N balance calculations

Manure excretion coefficients are usually, as in this calculation, fixed values that are not adjusted for changes in feeding regimes for milk and meat production. Furthermore, there can be considerable differences in excretion coefficients used among different countries (van Eerdt and Fong 1998), which can complicate comparisons among countries if the coefficients are not reliable. The variation in N excretion coefficients can be seen from Table 1, where the default values for OECD and Finnish coefficients for environmental authorities (Ministry of Environment 1998) and for greenhouse gas emission calculations (Statistics Finland 2006) are shown. Considering the coefficients for Finland, values calculated for greenhouse gas emission would probably be the most reliable as they are checked regularly on the basis of recommended animal feeding. In future studies the expertise of animal nutrition should be used in environmental nutrient balance studies when calculating the estimates for manure and nutrient excretion.

Concerning other N inputs, the N fertiliser use data that was based on sales statistics can differ from the amount actually applied to crops over a given year (Parris 1998). Biological N fixation is rarely studied in Finland and amounts of fixed N probably vary considerably among fields.

Estimation of ammonia volatilisation from manure is based on various coefficients that are dependent on manure storage and treatment. Manure storage and field application methods on farms are poorly documented in national statistics. Volatilised ammonia is readily absorbed by vegetation and soil and thus most volatilised ammonia can be redeposited close to the site of emission (Pitcairn et al. 1998). An alternative method for calculating ammonia volatilisation was suggested by Janzen et al. (2003), who assumed that 30% of soluble manure-N is volatilised and 30% out of that is later deposited on other than agricultural land. This results in 9% output of soluble manure-N from the agricultural system. Probably the OECD recommendation to use gross N balance derives from the difficulties in estimating ammonia volatilisation, which is an important element in net N balance.

Crop yield statistics are seldom absolute, especially in the case of grass production and grazing. Annual variation in N content of grains can also introduce error into the balances. Results from an annual survey of the Finnish Food Safety Authority (Salo et al. 2007) suggested that variation of N content in cereals was 0.3–0.5 percentage points over years and regions. Regional calculations could be improved by using these data.

Comparison among countries and regions

In the OECD Nitrogen Balance Database (OECD 2001) the highest national gross N balances in 1985–1997, 100–300 kg ha^{-1}, were for countries with intensive animal production (Netherlands, Belgium and Denmark) and intensive agriculture concentrated on small cultivated areas (Japan and South Korea). The majority of European countries are similar to Finland, with gross annual N balances of 50 to 100 kg ha^{-1}. Countries with large areas of extensive agriculture, such as Canada, have gross N balances as low as 17 kg ha^{-1} (Janzen et al. 2003). As the annual decrease in N balance in Finland was more than 2 kg ha^{-1} in 1990–2005 and net N balance reached 50 kg ha^{-1}, the decrease will most likely cease in the coming years.

In general, countries with high livestock densities and intensive agricultural production systems have the highest N surpluses. The overall trend in national N balance surpluses over the last decade is downwards or constant for most OECD countries (Parris 1998).

While an annual national N balance provides an impression of the performance of the agricultural sector as related to its use and management of N, there is usually significant spatial variation in N balances, largely attributable to variation in cropping and livestock production patterns and systems, soil types, topography, climatic conditions and farm management practices (Parris 1998). Lord et al. (2002) calculated a “farm gate” N balance of 140 kg ha^{-1} for agricultural grassland and 51 kg ha^{-1} for arable land in the United Kingdom. However, nitrate concentrations in rivers were generally greater in arable areas, which shows that N leaching is also dependent on land use, soil type and climate (Lord et al. 2002). Distribution of N surplus over fields within a farm affects N leaching because the relationship between field surplus and N leaching (Watson and Foy 2001, Salo and Turtola 2006) is one of increase after a certain threshold value is reached (van Beek et al. 2003, Korsaeth and Eltun 2000).

In Finland, the main production sector of the northern and eastern Rural Centres is milk production and these Centres had high N balances at the beginning of the 1990s. During the study period, the livestock density and manure N input decreased in most of these Rural Centres and this was associated with a clear decrease in mineral fertiliser input. The decreased mineral N fertiliser input is a combination of decreased N use for grassland and a shift towards cereal cultivation with lower N application rates compared with grassland. In some of these Rural Centres, the yield N uptake also slightly decreased, most probably due to the lower N uptake of cereals than of grasses. In southern Rural Centres dominated by cereal production, the decrease in mineral fertiliser input is the main cause of decreased N input and N surplus.

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References

Antikainen, R., Lemola, R., Nousiainen, J.I., Sokka, L., Esala, M., Huhtanen, P. & Rekolainen, S. 2005. Stocks and flows of nitrogen and phosphorus in the Finnish food production and consumption system. *Agriculture, Ecosystems and Environment* 107: 287–305.

Esala, M. & Larpes, G. 1984. Kevätviljojen sijoituslannoitus savimailla. *Maatalouden tutkimuskeskus. Tiedote* 2/84. 35 p.

Finnish Ministry of the Environment 1998. *Ohje kotieläintalouden ympäristönsuojelusta 30.9.1998*. 27 p. Cited 12 December 2006. Available on the internet: http://www.ymparisto.fi/download.asp?contentid=22354&lan=FI

Finnish Ministry of the Environment 2002. *National inventory report*. Finland's report on the greenhouse gas emission inventory to the European Commission . Common reporting formats (CRF): 1990–2001. Cited 12 December 2006. Available on the internet: http://www.ymparisto.fi/download.asp?contentid=5662&lan=EN

Grönroos, J., Nikander, A., Syri, S., Rekolainen, S. & Ekqvist, M. 1998. Maatalouden ammoniakkipäästöt. Abstract: Agricultural ammonia emissions in Finland. *The Finnish Environment* 206. 68 p.

Information Centre of the Ministry of Agriculture and Forestry. 1991–2005. *Yearbook of Farm Statistics.* Helsinki.

IPCC. 2002. *Special Report on Emissions Scenarios*. Cited 12 December 2006. Available on the internet: http://www.grida.no/climate/ipcc/emission/index.htm

Janzen, H.H., Beauchemin, K.A., Bruinsma, Y., Campbell, C.A., Desjardins, R.L., Ellert, B.H. & Smith, E.G. 2003. The fate of nitrogen in agroecosystems: An illustration using Canadian estimates. *Nutrient Cycling in Agroecosystems* 67: 85–102.

Korsaeth, A. & Eltun, R. 2000. Nitrogen mass balances in conventional, integrated and ecological cropping systems and the relationship between balance calculations and nitrogen runoff in an 8-year field experiment in Norway. *Agriculture, Ecosystems and Environment* 79: 199–214.

Kroeze, C., Aerts, R., van Breemen, N., van Dam, D., van der Hoek, K., Hofschreuder, P., Hoosbek, M., de Klein, J., Kros, H., van Oene, H., Oenema, O., Tietama, A., van der Veeren, R. & de Vries, V. 2003. Uncertainties in the fate of nitrogen I: An overview of sources of uncertainty illustrated with a Dutch case study. *Nutrient Cycling in Agroecosystems* 66: 43–69.

Kulmala, A. & Esala, M. 2000. Maatalous ja kasvihuonekaasupäästöt : Kirjallisuuskatsaus. Abstract: Agriculture and greenhouse gas emissions. Literature review. *Publications of Agricultural Research Centre of Finland. Series A* 76. 67 p. Cited 12 December 2006. Available on the internet: http://www.mtt.fi/asarja/pdf/asarja76.pdf

Kuusisto, E. 1997. Laskeuma. *Ympäristö* 3:1997. p 24.

Leppänen, S., Leinonen, L. & Anttila, P. 2000. *Ilmanlaatu tausta-asemilla 2000.* Ilmatieteen laitos, Ilmanlaatu. Cited 12 December 2006. Available on the internet: http://www.fmi.fi/kuvat/Ilmanlaatu00.pdf

Lord, E.I., Anthony, S.G. & Goodlass, G. 2002. Agricultural nitrogen balance and water quality in the UK. *Soil Use and Management* 18: 363–369.

Mäkelä-Kurtto, R. & Sippola, J. 2002. Monitoring of Finnish arable land: changes in soil quality between 1987 and 1998. *Agricultural and Food Science in Finland* 11: 273–284.

Mathieu, O., Lévêque, J., Hénault, C., Milloux, M.-J., Bizouard, F. & Andreux, F. 2006. Emissions and spatial variability of N_2O, N_2 and nitrous oxide mole fraction at the field scale, revealed with ^{15}N isotopic techniques. *Soil Biology and Biochemistry* 38: 941–951.

OECD Secretariat 1997. *National Soil Surface Nutrient Balances, 1985 to 1995.* Explanatory Notes. Table 2 Coefficients to convert livestock numbers into manure nitrogen quantities from national sources.

OECD/EUROSTAT 2003. *Gross Nitrogen Balances. Handbook. December 2003.* Cited 12 December 2006. Available on the internet: http://webdomino1.oecd.org/comnet/agr/aeiquest.nsf.

OECD 2001. *Nitrogen Balance Database*. Cited 12 December 2006. Available on the internet: http://www.oecd.org/agr/env/indicators.htm

Parris, K. 1998. Agricultural nutrient balances as agri-environmental indicators: an OECD perspective. *Environmental Pollution* 102: 219–225.

Pipatti, R., Tuhkanen, S., Mälkiä, P. & Pietilä, R. 2000. Maatalouden kasvihuonekaasupäästöt sekä päästöjen vähentämisen mahdollisuudet ja kustannustehokkuus. Abstract: Agricultural greenhouse gas emissions and abatement options and costs in Finland. *VTT Publications* 841. Espoo. 72 p. Cited 12 December 2006. Available on the internet: http://www.vtt.fi/inf/pdf/julkaisut/2000/J841.pdf

Pitcairn, C.E.R., Leith, I.D., Sheppard, L.J., Sutton, M.A., Fowler, D., Munro, R.C., Tang, S. & Wilson, D. 1998. The relationship between nitrogen deposition, species composition and foliar nitrogen concentrations in woodland flora in the vicinity of livestock farms. *Environmental Pollution* 102(S1): 41–48.

Regina, K., Syväsalo, E., Hannukkala, A.& Esala, M. 2004. Fluxes of N_20 from farmed peat soils in Finland. *European Journal of Soil Science* 55: 591–599.

Salo, T. & Turtola, E. 2006. Nitrogen balance as an indicator of nitrogen leaching in Finland. *Agriculture, Ecosystems and Environment* 113: 98–107.

Salo, T., Eskelinen, J., Jauhiainen, L. & Kartio, M. 2007. Reduced fertiliser use and changes in cereal grain weight, test weight and protein content in Finland in 1990–2005. *Agricultural and Food Science* 16: 407–420.

Statistics Finland, 2006. *Greenhouse gas emissions in Finland 1990–2004. National Inventory Report to the UNFCCC.* 15th April 2006. Cited 12 December 2006. Available on the internet: http://tilastokeskus.fi/tup/khkinv/nir_unfccc_2006.pdf

Syväsalo, E., Regina, K., Pihlatie, M. & Esala, M. 2004. Emissions of nitrous oxide from boreal agricultural clay and loamy sand soils. *Nutrient Cycling in Agroecosystems* 69: 155–165.

Tuori, M., K. Kaustell, Valaja, J., Aimonen, E., Saarisalo, E. & Huhtanen, P. 1996. *Rehutaulukot ja ruokintasuositukset*. Helsinki. 96 p.

Väisänen, J. 2000. Biological nitrogen fixation in organic and conventional grass-clover swards and a model for its estimation. Licentiate thesis. University of Helsinki. 42 p.

van Beek, C.L., Brouwer, L. & Oenema, O. 2003. The use of farmgate balances and soil surface balances as estimator for nitrogen leaching to surface water. *Nutrient Cycling in Agroecosystems* 67: 233–244.

van Eerdt, M.M. & Fong, P.K.N. 1998. The monitoring of nitrogen surpluses from agriculture. *Environmental Pollution* 102: 227–233.

Viljavuuspalvelu 2000. *Viljavuustutkimuksen tulkinta peltoviljelyssä.* Viljavuuspalvelu Oy. 32 p.

Vuorenmaa, J. 2005. Euroopan päästövähennykset alentaneet happamoittavaa laskeumaa. *Ympäristö* 8/2005: 18–19.

Vuorenmaa, J., Juntto, S. & Leinonen, L. 2001. Sadeveden laatu ja laskeuma Suomessa 1998. Abstract: Rainwater quality and bulk deposition in Finland in 1998. *The Finnish Environment* 468. 115 p.

Vuorenmaa, J., Rekolainen, S., Lepistö, A., Kenttämies, K. & Kauppila, P. 2002. Losses of nitrogen and phosphorus from agricultural and forest areas in Finland during the 1980s and 1990s. *Environmental Monitoring and Assessment* 76: 213–248.

Watson, C.J. & Foy, R.H. 2001. Environmental impacts of nitrogen and phosphorus cycling in grassland systems. *Outlook on Agriculture* 30: 117–127.

SELOSTUS

Maatalousmaan valtakunnallinen ja alueellinen typpitase Suomessa

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MTT Kasvintuotannon tutkimus

Maatalousmaan typpitaseella kuvataan typen käytön tehokkuutta ja maatalouden intensiteetissä tapahtuneita muutoksia. Pellon typpitasetta määritettäessä vähennetään peltoon päätyvistä ravinteista sadon mukana poistuvat ravinteet. Muutokset typen ylijäämässä kuvaavat typen kuormituspotentiaalin muutoksia. Suuren ylijäämän voidaan olettaa lisäävän kuormitusriskiä ilmaan ja veteen. Valtakunnalliset ja maaseutukeskuskohtaiset typpitaseet vuosilta 1990–2005 laskettiinkin muun muassa ympäristötuen vaikutusten arvioimiseksi.

Tutkimus toteutettiin siten, että koko Suomea ja maaseutukeskuksia koskevista tilastotiedoista määritettiin väkilannoitteissa ja karjanlannassa pellolle päätyvän kokonaistypen määrä hehtaaria kohden. Haihtuvan NH_3-typen määrä laskettiin karjanlannasta eläinlajien ja lannankäsittelyvaiheiden mukaisten päästökertoimien avulla ja vähennettiin luku pellon saamasta typestä. Myös väkilannoitteiden ammoniumin haihtuminen (0,6 % niiden sisältämästä typestä) vähennettiin pellolle päätyvästä typpimäärästä. Tärkeimpien viljelykasvien pinta-alat ja sadot sekä niiden typpipitoisuus määritettiin tilastotietojen ja kirjallisuuden avulla. Tilastotiedot eläinten lukumääristä ja viljelykasvien pinta-aloista käsiteltiin maaseutukeskuksittain. Biologinen typensidonta arvioitiin typpeä sitovien viljelykasvien pinta-alojen ja tutkimustulosten perusteella, ja typpilaskeuman suuruus määritettiin tehdyistä mittausseurannoista. Kaikki laskelmat tehtiin vuosille 1990–2005.

Pellolle päätyvän typen määrä on pienentynyt 1990-luvun alusta vuoteen 2005 mennessä 175 kg:sta 120 kg:aan hehtaaria kohden. Tämä johtuu lähinnä typpilannoitteiden käytön vähenemisestä. Sadon mukana poistuvan typen määrä on vaihdellut kasvukauden suotuisuudesta riippuen 65 kg:sta 98 kg:aan/ha. Taseen ylijäämä on vähentynyt tarkasteluajankohtana lähes 90 kg:sta noin 50 kg:aan hehtaaria kohden. Tarkastelujakson alussa karjatalousvaltaisten alueiden ylijäämät ovat olleet merkittävästi muita korkeimpia. Ne ovat kuitenkin selvästi pienentyneet 1990-luvun loppua kohden. Vuosittaiset satovaihtelut näkyvät typpitaseessa selkeästi.

Typpitaselaskennan merkittävimmät epävarmuustekijät typen määrää kasvattavalla puolella ovat lannan käyttömäärä ja sen typpipitoisuus, poistumispuolella taas nurmisatojen suuruus ja niiden typpipitoisuus. Tilastotietojen pohjalta tehtävässä laskennassa absoluuttisia arvoja tärkeämpää onkin tarkastella aineistossa ajan suhteen tapahtuvaa muutosta.

Valtakunnallisen ja alueellisen typpitaseen arvioiminen antaa kuvan tarkasteluajanjakson aikana tapahtuneista typpitaseen muutoksista. Typpitaseen ylijäämän pieneneminen merkitsee maataloudesta peräisin olevan typen kuormitusriskin vähenemistä. Vaikka kuormitusriskin pieneneminen ei välttämättä näy vesistöissä tehdyissä mittauksissa, typen käyttö maataloudessa on kuitenkin vähentynyt.