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Assessing the risk of agricultural non-point source nitrogen pollution

Development of a nitrogen index for Norway

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Sammendrag

Denne rapporten presenterer en nitrogenindeks for vurdering av risiko for diffus nitrogenforurensing fra landbruket. Det er et enkelt verktøy som skal brukes på skiftenivå. Som input kreves kun data som er allment eller offentlig tilgjengelig, eller som den enkelte bonde kan framskaffe. N-indeksen kan brukes til å identifisere arealer med høy risiko for N-tap, og dessuten som et hjelpemiddel ved vurdering og valg av optimal drift. Nåværende versjon av N-indeksen ble utviklet for et lite nedbørfelt i sørøst-Norge, Skuterudfeltet. Alle faktorer som anses som betydningsfulle for N-tap, og som kan påvirkes av mennesker, ble forsøkt inkludert. N-indeksen formuleres som summen av løst N, partikulært N og episodetap av N fra husdyrgjødsel, minus N-retensjon, for øyeblikket satt lik 0. Løst N, eller N tilgjengelig for utvasking, er lik forskjellen mellom tilført og bortført N. Tilført N omfatter N fra deposisjon, N-fiksering, mineralgjødsel, husdyrgjødsel, plantemateriale og jordarbeiding. Bortført N omfatter N-opptak i planter sommer og høst, denitrifikasjon og halmbehandling. Partikulært N beregnes fra organisk materiale i jord og erosjonsrisiko. Episodetap av N fra husdyrgjødsel omfatter foreløpig bare organisk N, og avhenger av mengde husdyrgjødsel og når den spres. N-indeksen ble beregnet for alle skifter i Skuterudfeltet for de agrohydrologiske årene 1994-95 til 2002-03. I middel for denne perioden så N-indeksen ut til å fange opp de viktigste effektene på N-tap relativt bra. For 2001 ble fire driftsscenarier testet: 1) endre gjødslingsnivå til normnivå (tilpasset plantenes N-behov), 2) dyrke fangvekst, 3) la åkeren stå i stubb etter høsting, og 4) høstpløye alle skifter. I dette tilfellet var scenariet med normgjødsling det mest effektive, fulgt av fangvekstscenariet. Flere kunnskapshull ble avdekket under utvikling av N-indeksen, og N-indeksen krever dermed videre forbedring. Den bør videre kalibreres og valideres utenfor Skuterudfeltet for å tilnærme seg en N-indeks som kan brukes på all dyrka mark i Norge. På sikt er det også ønskelig å integrere N-indeks og gjødslingsplan.

Summary:

This report presents a nitrogen index for assessing the risk of agricultural non-point source nitrogen (N) pollution. It is a simple tool, to be used on field scale, and requiring input that is generally available from public sources or from the individual farmers. It can be used for identifying areas with high risk of N loss, and it can be used to aid the assessment and selection of best management practices. The current version of the N-index was developed for a small agriculture dominated catchment in South-east Norway, the Skuterud catchment. All manageable factors considered important for N loss were sought included in the N-index. The N-index is formulated as the sum of dissolved N, particle bound N and incidental N loss from manure, minus N retention, presently set equal to 0. Dissolved N, or N available for leaching, equals the difference between N sources and N removal. N sources include N from deposition, N fixation, fertiliser, manure, plant material and tillage. N removal includes plant N uptake in summer and autumn, denitrification and residue management. Particle bound N is calculated from soil organic matter content and erosion risk. Incidental N loss deals with organic N in manure only, and depends on the amount of manure and timing of application. The N-index was calculated for all fields in the Skuterud catchment for the agrohydrological years 1994-95 to 2002-03. Averaged over this period, the N-index appeared to capture the most important management effects on nitrogen loss reasonably well. For the year 2001, four different management scenarios were tested: 1) changing fertiliser levels to the recommended norm level (equal to crop demand), 2) introducing catch crops where possible, 3) leaving all fields in stubble after harvest, and 4) ploughing all fields in autumn. In this case, the norm fertiliser scenario was by far the most efficient, followed by the catch crop scenario. The N-index awaits further improvement, as several knowledge gaps were identified during its development. It should also be calibrated and validated outside the Skuterud catchment, to make it applicable to all agricultural land in Norway. The final aim of the N index is to be included in the nutrient management plan for farmers.

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Preface

This report presents the first step in developing a nitrogen index for assessing the risk of agricultural non-point source nitrogen pollution. Its development has been part of the INTRA project – "Integrated risk assessment for the transport of particles, nutrients and pesticides in agricultural catchments" (project number 159255/S30), funded by the Norwegian Research Council. Further development of the nitrogen index is required for making it valid for conditions not accounted for so far, and to make it available to the public.

Contents

1. Introduction

It is of great importance to direct attention toward reducing agriculture nonpoint-sources of the plant nutrients, nitrogen and phosphorus. Although best irrigation and nitrogen management practices have been used, increases in worldwide use of nitrogen fertilizer combined with average nitrogen use efficiencies of 50 percent have contributed to increased leakage from the N-cycle (Schaffer and Delgado, 2002). A framework is needed to identify the relative risk of diffuse loss of nitrogen at field scale in order to make a selection of appropriate best management practices and to maximise their effect. In order to meet the demands of end-users, some major requirements and qualities must be fulfilled:

- The tool should be directed primarily towards two main objectives:
    - To identify high-risk areas within catchments
    - To evaluate best management practices
- The tool should estimate the risk of nitrogen loss from field to open stream. The output need not necessarily be an absolute load figure, a class or continuous rank system (e.g. "low", "medium" and "high") is preferred.
- The tool should be operated at the scale of fields, landscape units and subcatchments, since these are the scales at which measures usually will be implemented.
- Input data should be readily available, e.g. directly from farmers or census, from digital maps (soil maps), etc.
- All factors that influence nitrogen loss and at the same time relevant for management should be included, sources, sinks and transport factors alike.
- The approach should be simple – it should be easy to understand, easy to apply, time- and cost effective. It should be ready for use to managers, without the need for calibration and validation.

The concept of a nitrogen index (N-index) potentially complies with all these points. It does not explicitly rely on exact or detailed physical-mathematical descriptions of the system, as in mechanistic/ process-based models. Nor does it rely strictly on statistically significant relationships between factors and outputs, as in empirical models. Such models can however provide knowledge and quantitative data on the relative importance of different factors, and serve as tools in developing the index.

Existing N-indices vary in approach and complexity. Some focus primarily on the transport process, taking only the availability of water for percolation into account and deriving the nitrate leaching risk from this, others consider only sources and sinks for nitrogen, and partly management, without considering soil hydrology. A summary of this type of N-indices is given by Schaffer and Delgado (2002). N-indices including both source and transport also exist, e.g. the N index by Heathwaite et al., (2000), presented in Table 1, and the Ontario N index (Goss et al., 1999; OMAFRA, 2002). Although not referred to as an N-index, the method of Aronsson and Torstensson (2004) to estimate nitrogen leaching from fields can also be put in this group. The general impression is that these N-indices are all, at least partly, based on an nitrogen balance approach.

The N-index of Heathwaite et al. (2000), shown in Table 1, includes soil texture and permeability as transport factors, and fertiliser, manure and timing and method of application of these as source factors. Effects of e.g. tillage and crops are not considered. The source factors tend to govern the magnitude of nitrogen loss, while transport factors dictate the delay caused by percolation through various soil horizons (Mc Dowell et al., 2000).

Table 1. The N-index to rate the potential loss in leaching from site characteristics determining source and transport factors (Heathwaite et al. 2000).

Factors	Leaching potential from transport factors (value)				
	None (0)	Low (1)	Medium (2)	High (4)	Very High (8)
Texture	Clay	Clay loam to silty clay loam	Loam to silt loam	Loamy find sand to coarse sandy loam	Sand
Permeability (cm h^{-1})	<1,5	1,6-4	4,1-14,9	15-50	>50
	Leaching potential from source factors (value)				
Fertilizer N-rate (kg ha^{-1})	Non applied	1-50	51-150	151-300	>300
Application method for fertilizer	None	Placed with planting	Incorporated immediately before crop	Surface-applied > 3 mo before crop or incorporated < 3 mo before crop	Incorporated > 3 month before crop
Manure N-rate (kg ha^{-1})	Non applied	1-50	51-150	151-300	>300
Application method for manure	None	Placed with planting	Incorporated immediately before crop	Surface-applied>3 mo before crop or incorporated < 3 mo before crop	Incorporated > 3 month before crop
N-index rating = (Texture rating × Permeability rating) × ∑ (Source characteristic × Weight)					

Goss et al. (1999), in their nitrogen index, used an N-balance approach to estimate the amount of nitrogen available for leaching (source factor) and regression relationship were used to estimate the amount of deep percolation. The nitrogen index approach presented by Goss et al. (1999) has been described in detail by OMAFRA (2002). Factors considered include crop characteristics, anticipated yield and nitrogen use, fertiliser, manure (type of manure, manure incorporation, gaseous losses, incidental nitrogen loss), soil characteristics (transport rate, denitrification, hydrological soil group), partitioning of precipitation at the soil surface into runoff and deep percolation, presence of field drains, slope, average weather conditions and seasonal risk. The OMAFRA nitrogen index includes two levels: A simple paper form that allows farmers to determine the application rates of manure and fertilizer that minimize the risk of nitrate leaching, and a detailed computerized software version that provide a more comprehensive assessment and indicate options for improved management.

The fundament for the nitrogen leaching tool of Aronsson and Torstensson (2004) is a general leaching risk, "background leaching", for specific soils in certain climatic regions, with a cereal crop with nitrogen applied as commercial fertiliser in appropriate amounts and with soil tillage in September to October. This reference state was calculated using model simulations for 289 communities in Sweden and 5 soil classes. The total risk of nitrogen leaching is then calculated using multiplicative and additive factors for e.g. tillage timing, dose of fertiliser nitrogen in relation to recommended dose, time and technique for spreading of manure, nitrogen fertilization in autumn, nitrogen uptake in crops during autumn and residual effects of crops.

The objective of this work

Our main intention is to develop a simple indexing system that operates at the field scale. It should highlight high risk situations and accurately show differences in risk of nitrogen loss between different management practices and soils. It is important that the nitrogen index can be applied on a farm-by-farm basis at the field scale in close connection with the nutrient management plan. The nitrogen index must be designed in a way that can help to identify specific areas within a catchment area that contribute most to loss of nitrogen from agricultural land to surface waters and provide site specific, yet flexible management tool to help minimize these losses.

2. Case study area: the Skuterud catchment

The Norwegian nitrogen index was developed using information from a 450-ha catchment in south-eastern Norway: the Skuterud catchment (central coordinates of 59° 66' N 10° 78' E), dominated by agricultural land use (Figure 1 and 2). The average precipitation is 785 mm yr^{-1} and the average temperature 5.3ºC, considering the agrohydrological year which lasts from May 1 to April 30. Average stream flow in the period 1994-2003, measured through the Agricultural environmental monitoring programme in Norway (JOVA), was 533 mm yr^{-1} (Skjevdal et al., 2004). In the same period, the average load of total nitrogen measured in the stream was 45 kg ha^{-1} yr^{-1}, of which 35 kg ha^{-1} yr^{-1} (78 %) was in the form of nitrate (NO_3^-).

The predominant soil types are developed on marine clay and sandy shore deposits. According to the soil map from the Norwegian Institute for Land Inventory (NIJOS, 2006), the most widespread soils are classified as Albeluvisols, Luvisols, Umbrisols, Cambisols and Gleysols in World Reference Base for Soil Resources (WRB) classification system. Regosols, Podsols, Arenosols and Anthrosols are also found. The soil texture classes of the agricultural areas vary from coarse sand to silty clay loam. Slopes in the catchment vary from one to 20%. Most fields have been artificially drained, typically with 0.8 m drain depth and 8 m drain distance.

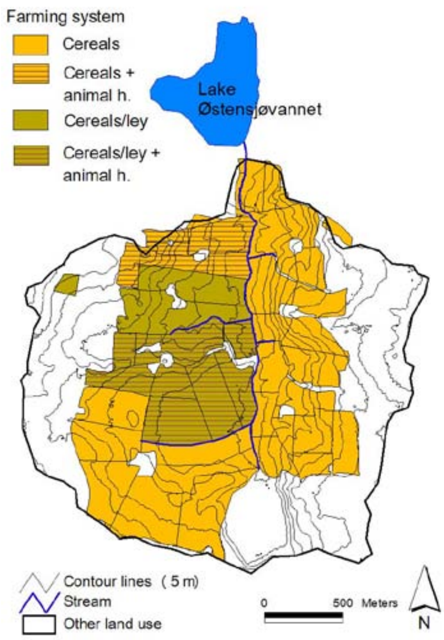

Figure 1 (above). Aerial photograph of parts of the Skuterud catchment.

Figure 2 (right). Map of the Skuterud catchment, with farming systems.

The Skuterud catchment is typical for agricultural areas in south-eastern Norway. Agricultural land use constitutes 60% of the catchment area with 32% forest and 8% urban and other areas. The agricultural production is dominated by cereals (Figure 3). On average for the period 1994-2002, spring sown cereals covered 63 % of the agricultural land area, and winter cereals 26 %. Cereal yields were around 5 tons ha^{-1}, varying between approximately 3 and 7 tons ha^{-1} (Figure 4). The remaining 11 % of the area included oil seed, ley, potatoes and peas. There is also a small area of pasture in the catchment.

The average amount of nitrogen supplied with fertilizer (Figure 5) was 144 kg ha^{-1} in 1994-2002, with lowest amounts on oats and barley (120 kg ha^{-1}), and higher amounts on winter rye (143 kg ha^{-1}), wheat and oil seed (both 155 kg ha^{-1}). The highest amounts were applied to ley (180 kg ha^{-1}). There was generally less variation in application rates between years on oats and barley than on the other crops.

Split application of fertiliser was fairly common on wheat, with one application in spring, and up to three additional applications in summer.

In the period 1994-2002 two farms applied manure to their fields. The application rate of manure nitrogen was highly variable (Figure 5), on average in the catchment between 6 and 178 kg N ha^{-1} (5 – 50 tons manure ha^{-1}, mean 33 tons ha^{-1}). Types of manure used were pig and cattle slurry, and solid cattle manure.

About 43 % of the area was tilled in spring or was spring crops under direct drilling (Figure 6). About 7 % was directly drilled winter cereals. Ley covered 6 %. Catchcrops covered 0.5 % only. Tillage timing for winter cereals was primarily in early autumn, autumn tilling for spring crops was spread more throughout both early and intermediately late autumn.

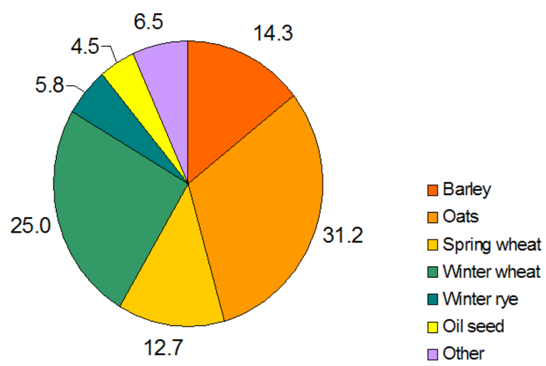

Figure 3. Crop distribution (% of agricultural land) in the Skuterud catchment, mean 1994-2002.

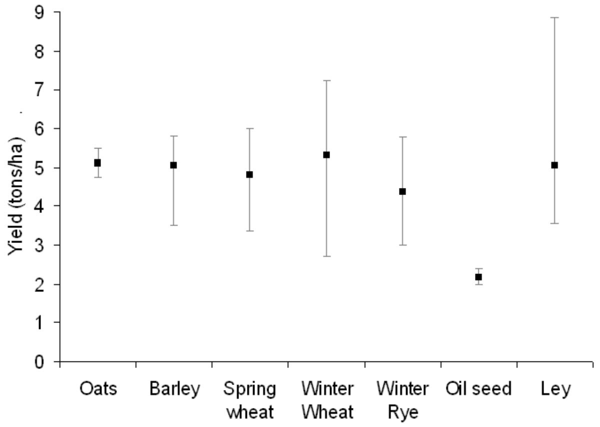

Figure 4. Crop yields, catchment mean 1994-2002. The bars represent minimum and maximum mean catchment yields from the same period.

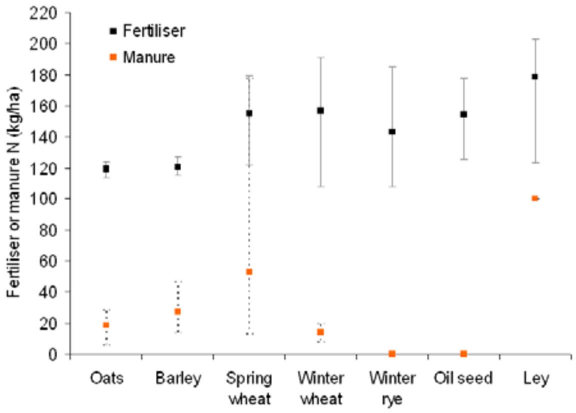

Figure 5. Nitrogen applications in fertiliser and manure, catchment mean 1994-2002. The bars represent minimum and maximum mean catchment fertiliser/manure nitrogen from the same period.

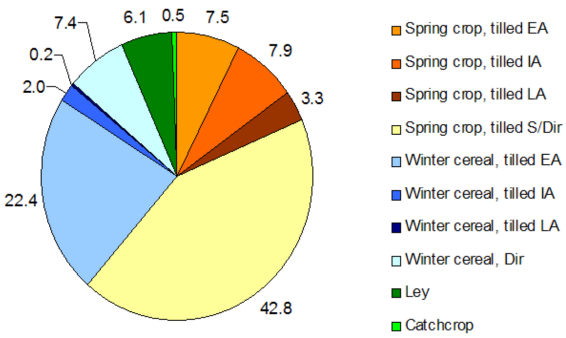

Figure 6. Tillage and autumn crop cover (% of agricultural land) in the Skuterud catchment. S = spring, Dir = direct drilling, EA = early autumn, IA = intermediate autumn, LA = late autumn.

3. The nitrogen index

The nitrogen cycle (Figure 7), including all the important processes involved in generating a nitrogen surplus (or deficit), forms the basis for the N-index. The nitrogen index (N-index) consists of four modules: i) dissolved nitrogen, ii) loss of particulate nitrogen iii) incidental nitrogen loss and iv) retention through the landscape, summarized as follows:

N-index = dissolved N + particulate N + incidental N loss from manure - N retention

Dissolved N, described in section 3.1., is the nitrogen surplus or deficit resulting from the addition and removal of nitrogen to/from the soil (N source – N removal). The surplus can be lost by leaching. Particulate N (section 3.2.) is the amount of particle bound nitrogen lost by erosion. Incidental N (section 3.3.) is the amount of nitrogen in manure lost by surface runoff or by leaching through macropores. N Retention (section 3.4.) is the holding back of surface nitrogen on the field and reduction of nitrogen that has been leached through the soil profile by processes in drainage systems and water bodies (streams, groundwater, etc). At present, the output from the N-index is continuous values comparable to loads. These values may be classified into nitrogen loss risk classes. The N-index applies to agrohydrological years, in Norway defined from May 1 to April 30.

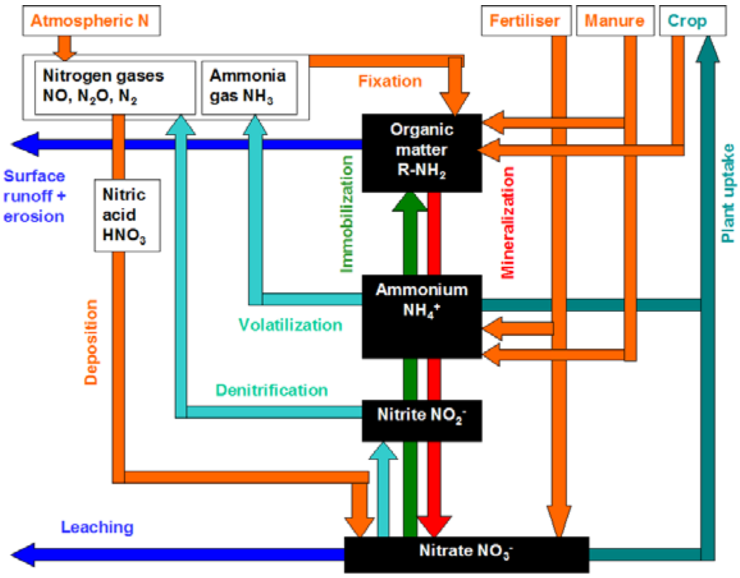

Figure 7. Nitrogen processes in soil.

3.1 Dissolved nitrogen

The estimated loss of dissolved N (primarily nitrogen leaching) was based on a nitrogen balance approach and the potential risk is related to the nitrogen surplus. The nitrogen balance consists of nitrogen sources minus nitrogen removal and the factors are evaluated in terms of a nitrogen load (kg N ha^{-1}). The assumption for this approach is that the system is in equilibrium; that is there will be no changes in "natural" soil organic content in the short or long term. Manure and crops, and tillage-induced mineralization, are not considered "natural" in this case, and can therefore have a short-term effect on the nitrogen pool.

All factors considered of significant importance for nitrogen loss and relevant for management have been included, though it may be difficult to find simple estimates for some of these factors and their relative importance or weights.

3.1.1 Nitrogen sources

The nitrogen sources to dissolved N are presented in Table 2.

Table 2. Input sources in the dissolved N-index

<table>
<tr><th colspan="6">N source</th></tr>
<tr><td>Deposition N</td><td colspan="5">N concentration x precipitation</td></tr>
<tr><td>Fertiliser N</td><td colspan="5">Fertiliser/mineral N amount</td></tr>
<tr><td>N fixation</td><td colspan="5">Not yet included</td></tr>
<tr><td>Manure N</td><td colspan="5">Manure amount × (inorganic × correction inorganic N + organic N × correction organic N)</td></tr>
<tr><td>Correction inorganic N</td><td>0.9
Direct incorporation</td><td colspan="2">0.6
Incorporation 1-18 hours</td><td colspan="2">0.3
Incorporation >18 hours or surface applied</td></tr>
<tr><td>Correction organic N</td><td>0.18
Incorporation autumn</td><td colspan="2">0.6
Incorporation spring/summer</td><td colspan="2">0.1
Surface applied spring/summer</td></tr>
<tr><td>Organic N from previous year</td><td colspan="5">Manure applied previous year × organic N content × (1- correction organic N previous year) – incidental N loss from manure previous year</td></tr>
<tr><td>Winter crop N</td><td colspan="5">0.75 × N uptake the previous autumn</td></tr>
<tr><td>Tillage N</td><td>5
Tillage early autumn</td><td>3
Tillage mid-autumn</td><td>1
Tillage late autumn</td><td>0
Spring tillage</td><td>0
No tillage</td></tr>
<tr><td colspan="6">N source = deposition N + fertiliser N + N fixation + manure N + organic N from previous year + winter crop N + tillage N</td></tr>
</table>

Deposition N

Data for nitrogen deposition can be obtained from the Norwegian Institute for Air Research (NILU). Løken, 50 km east of Ås, was the most representative station measuring nitrogen deposition, and data for the Skuterud catchment were taken from this station. The nitrogen deposition at Løken varied from 4.1 to 6.0 kg ha^{-1} in the years 1994 – 2002.

Fertiliser N

Fertiliser or mineral nitrogen application (kg N ha^{-1}) is provided by the farmer. The average application of fertiliser-N varied from 74 to 240 kg/ha in the Skuterud catchment in the period 1993 – 2004.

Manure N

Manure contains both inorganic nitrogen (NH_4^+ - ammonium) and organic nitrogen compounds. The amount of manure N, provided to the N-index by the farmer, was multiplied by the fractions of inorganic and organic nitrogen in the relevant type of manure (Table 3). The fraction of inorganic manure was corrected for time until incorporation, as the ammonium is subject to volatilization to ammonia gas after application. Ammonia gas losses increase as time until incorporation increases. Organic nitrogen was also corrected for effects of incorporation on mineralization of the organic nitrogen to more mobile inorganic nitrogen compounds (ammonium and nitrate, NO_3^-). This correction factor depends on the season in which the manure is applied. Incorporation in spring and summer gives the highest release of inorganic nitrogen due to favourable temperature conditions. Surface application in spring and summer gives considerably lower availability of nitrogen because the manure to a lesser extent is in contact with the mineralising soil organisms. Manure incorporated in autumn is less degradable because the soil temperature is lower. Fractions of organic and inorganic nitrogen and their correction factors were derived from "Gjødslingshåndbok" (Fystro et al., 2006). After-effects of organic nitrogen in manure was taken into account by transferring the remains of previous year's applied organic N, with incidental nitrogen losses from manure the previous year subtracted (see section 3.3.), to the present year.

Table 3. Table values for amount of inorganic and organic nitrogen in different manure types (Fystro et al., 2006).

Type of manure	Dry matter (%)	Inorganic N (kg tons^{-1})	Organic N (kg tons^{-1})
Cattle, slurry	8	2.3	1.6
Cattle, slurry (gylle)	4	1.2	0.8
Cattle, solid	20	1.3	3.3
Liquid manure (land)	3	4.7	0.2
Pig, slurry	8	4.2	1.8
Pig, solid	20	2.0	4.0
Sheep/goat, solid	24	2.0	6.0
Sheep/goat, slurry	12	3.3	2.7
Hen, solid	33	5.5	9.0
Hen, slurry	15	5.0	4.0
Broiler, with litter	50	4.5	13.5
Fur-bearing animals	25	6.5	7.5
Horse	28	1.0	4.5
Sewage sludge	25	2.0	2.5
Silage effluent	4	0.4	1.4

Winter crop N

Nitrogen taken up by catch crops, ley and winter cereals in autumn is often released in winter and spring due to freeze/thaw damage of the plant material. Furthermore, catch crops also add nitrogen to the nitrogen pool when incorporated in late autumn or spring. Aronsson (2000) found that 20 – 30 % of the nitrogen in catch crops were released during the first growing season after incorporation. It was assumed that 75 % of the nitrogen uptake from the previous autumn is made available for the input source pool.

Tillage

Tillage promotes decomposition of organic matter with consequent release of mineral nitrogen because physically protected pools of organic nitrogen and carbon are exposed and become available for microbial degradation when macroaggregates are disrupted (Ladd et al. 1993, Cambardella and Elliott 1993, Six et al. 2002, Alan and Hons 2005). The timing of tillage has shown to be of large importance for nitrogen release and nitrogen leaching. Field and plot experiments have shown that nitrogen leaching increases when tillage is carried out in early autumn relative to late autumn or spring (Eltun and Fugleberg 1996, Lundekvam 1997, Hansen and Djurhuus 1997, Stenberg et al. 1999, Korsæth et al. 2002, Aronsson and Torstensson 2003, Aronsson et al. 2003). The increased nitrogen leaching is usually attributed to stimulated mineralization in early autumn because the soil is warmer and the microbial activity higher at this time of the year. Korsæth et al. (2002) used a simulation model to simulate nitrogen leaching from a system with wheat and incorporation of a green manure (white clover)/barley straw mixture, and found that ploughing on September 15, October 15 and November 15 resulted in 23, 5 and 1 kg ha^{-1} higher nitrogen leaching respectively than spring ploughing. Lundekvam (1997) observed that nitrogen losses from a field plot were reduced by 6 – 10 kg ha^{-1} when postponing tillage from autumn to spring, and this was explained by higher permeability and a larger amount of subsurface flow in autumn, and larger nitrogen release (mineralization) in autumn ploughed soil. Effects of tillage timing were implemented into the input table of the N-index as a fixed amount of nitrogen to be added to the other inputs. No tillage was set as a reference state with no effect on the nitrogen pool. Spring tillage was set equal to no tillage. Autumn tillage was assumed to increase the input by 1, 3 and 5 kg ha^{-1} for late (> October 15), intermediate (September 15 – October 15) and early (< September 15) tillage timing respectively. Better documented figures should be used in the future improvement of the N-index.

N fixation
Fixation of nitrogen in plant roots of legumes (e.g *Rhizobium* sp.) and in soil bacteria (e.g. *Azotobacter* sp.) can be an important nitrogen source, but was not included in this version of the N-index. This will be included in the future. Note that fixation by legumes is small when sufficient amounts of nitrogen is available from other sources.

Organic matter
Organic matter is a source of nitrogen through the process of mineralization, which involves microbial decomposition of organic nitrogen to inorganic nitrogen. Net mineralization can range from 50 – 130 kg N ha^{-1} yr^{-1} for cropped soils with relatively low organic matter content, to > 400 kg N ha^{-1} yr^{-1} for fertilized pasture (Jarvis et al., 1996). In Norway the potential release of nitrogen from soil is reported to 10 – 100 kg ha^{-1} yr^{-1} (Solberg, 2003). Nitrogen release from mineralization will be included in the N-index later.

3.1.2 Nitrogen removal

The removal of available nitrogen from the soil is presented in Table 4.

Table 4. Output in the dissolved N-index

Output				
Plant N uptake summer	Crop yield x % N in grain + correction split application			
Correction split application	0 No		5 Yes	
Plant N uptake autumn	0 No winter crop	25 Catch crop	20 Ley	15 Winter cereals
Straw N	0 Incorporated	Amount of straw × % N in straw Removed		
Denitrification N	(0.081 x % clay + 0.043 x % org. matter - 0.399) x drainage			
Drainage correction	1			
Output = Plant N uptake summer + 0.75 × plant N uptake autumn + straw N + denitrification N				

Plant uptake
Plant uptake of nitrogen in summer was calculated by multiplying the expected yield, provided by the farmer, with the fraction of nitrogen in grain (values for different crops are presented in Table 5). An amount of 5 kg N ha^{-1} was added if split applications were carried out on cereals, because split applications often lead to an increased amount of protein, and thereby amount of N, in the grain of cereals.

Table 5. Nitrogen content (%) in grain and straw of different agricultural crops. Figures from the database of the Norwegian Environmental Agricultural Monitoring Programme.

Crop	N (%) in grain	N (%) in straw
Barley	1.75	0.31
Oats	1.75	0.32
Spring wheat	2.0	0.31
Winter wheat	2.0	0.31
Winter rye	1.75	0.30
Spring canola	3.4	0.72
Spring rape	3.4	0.72
Winter rape	3.4	0.72
Ley	3.2	0.25
Cereals with pea underseed	1.8	0.24
Peas	3.3	0.39
Potatoes (late)	0.31	0.05

Winter crop N

Keeping the field crop covered during autumn and winter potentially reduces the risk of nitrogen leaching due to an extended time period for crop nitrogen uptake. This effect was implemented in the N-index by adding a crop specific nitrogen amount to the outputs. Positive effects of catch crops on nitrogen leacning has been reported by e.g. Aronsson (2000), Aronsson and Torstensson (2003), Aronsson, Torstensson and Linden (2003), Bergström and Jokela (2001). Catch crops were assumed to be the most efficient in removing nitrogen from the soil in autumn, followed by ley and winter cereals. The nitrogen amounts taken up by these different crops were based on results from field and lysimeter experiments in Norway (Hiitola and Eltun 1997, Lyngstad and Børresen 1997, Hiitola 1997, Molteberg et al., 2005). One adverse effect that was not taken into account in the present version of the N-index, is that catch crops may compete with the main crop and cause decreased crop yields (Molteberg et al., 2005).

Straw

Incorporation of crop residues or straw during tillage potentially decreases the nitrogen availability as straw has a high C:N-ratio, resulting in temporary nitrogen limitations owing to microbial immobilization (Jenkinson, 1985; Addiscott and Dexter, 1994). It is difficult to find quantitative data for the significance of this process, as existing research is inconclusive or ambiguous. Thomsen and Christensen (1998) found that straw incorporation caused more nitrogen to be retained in the soil by immobilization, but leaching was not significantly reduced. According to Johnsson (pers. comm.) there were no clear effects of straw incorporation in a three-year experiment in Sweden. Therefore this factor was set to 0 for incorporation of straw. Removal of straw implies removal of N, and this amount was calculated by multiplying the amount of straw, assumed to equal the crop yield, with the percentage nitrogen in straw.

Denitrification

The process of denitrification transforms leachable nitrate and nitrite into nitrogen gases, which are lost to the atmosphere. The denitrification rate depends on many factors, the main factor being soil water content, which again depends on soil physical properties and drainage conditions. Barton et al. (1999) report in a review on denitrification in agricultural and forest soils that the in situ annual denitrification rate varies from 0 - 239 kg ha^{-1} yr^{-1}. The highest rates were reported for irrigated and nitrogen fertilized agricultural soils. The mean annual denitrification rate for agricultural soils was estimated to 13 kg ha^{-1} yr^{-1}. Due to lack of appropriate data for Norwegian conditions, a preliminary approach was used for the present version of the N-index: Denitrification was calculated from a linear relationship with clay and organic matter content, based on simulations carried out using the Swedish model SOILNDB (Johnsson et al., 2002). With this approach the estimated denitrification rate varied from 2 – 23 kg ha^{-1} in the Skuterud catchment (Figure 8). Clay and organic matter content can be obtained from soil sample analyses. Alternatively, they can be derived from the soil maps of the Norwegian Forest and Landscape Institute, which provide information on soil texture classes and ranges for organic matter. In further development of the N-index it may be convenient to include discrete denitrification figures for texture and organic matter classes instead of (or in addition to) the continuous function used here.

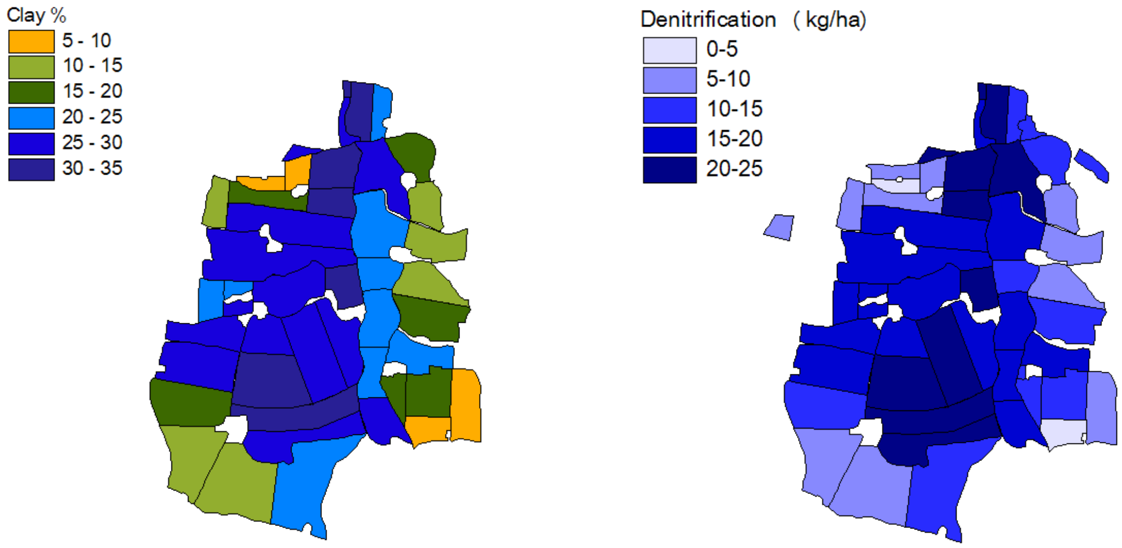

Figure 8. Field values for clay content (mean values calculated from soil samples) and denitrfication calculated from clay and organic matter content.

Drainage
Soils with high clay content are often drained to lower the water table so that soil aeration and trafficability are improved. Drainage decreases the denitrification rate due to more aerobic conditions. To exemplify: In one experiment drainage limited denitrification emissions to 65 % of the emissions from undrained soil (Colbourn and Harper, 1987). The effect of artificial drainage was implemented in the N-index as a correction factor on the denitrification. In the present version of the N-index this factor was set to 1, a reference value representing artificial drainage with drain pipes at 0.8 – 1 m depth and 8 – 10 m distance between the drain pipes, corresponding to the most common situation in Skuterud fields. There is not enough documentation on how drainage influences denitrification and nitrogen leaching in Norway, so research is needed for developing this factor further.

3.2 Transport of particulate nitrogen

The amount of particulate nitrogen is calculated from the soil nitrogen content and particle loss:

Particulate N = % N in soil × particle loss

The nitrogen content is derived from soil organic matter and the particle loss from erosion risk, as described in the following paragraphs.

3.2.1 Soil nitrogen content

The transfer of particulate nitrogen was calculated from the estimated erosion risk combined with the total nitrogen content in the soil. Soil nitrogen content is usually not part of the routine analyses carried out for farmers and must therefore be obtained from other sources. For arable land in the Skuterud catchment, measured data on topsoil nitrogen and organic matter content were available from a sample grid with 100 m spacing. Data analyses revealed a linear relationship between organic matter and nitrogen content. Field mean organic matter content is shown in Figure 9A, and the relationship between organic matter and nitrogen in Figure 9B. This relationship was included in the N-index so that the nitrogen content can be estimated from organic matter content, which is more often available from farmer's soil analyses.

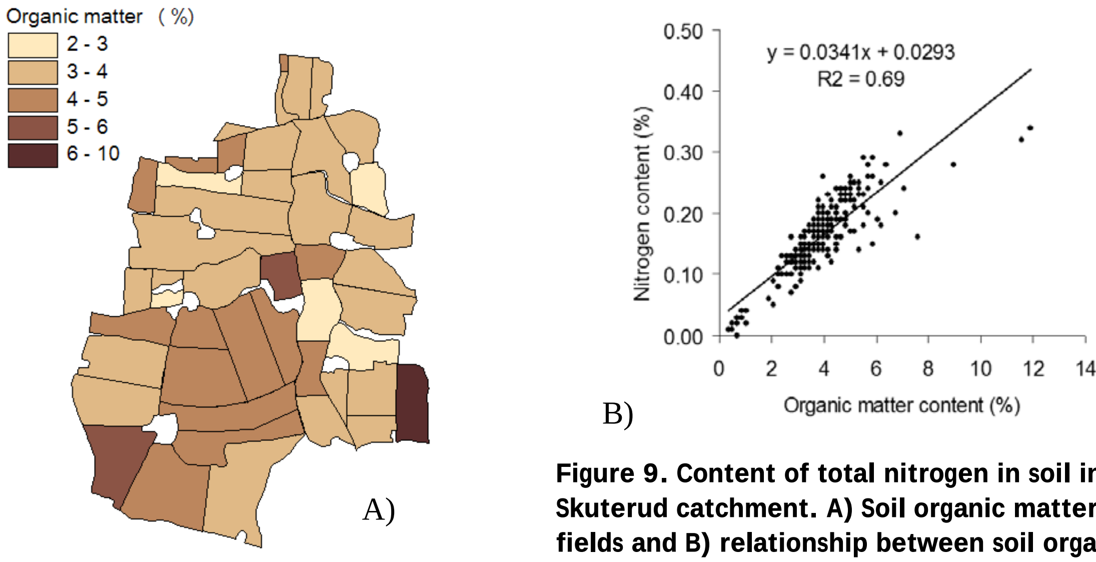

Figure 9. Content of total nitrogen in soil in the Skuterud catchment. A) Soil organic matter for fields and B) relationship between soil organic matter and nitrogen content in sampling points.

3.2.2 Erosion risk and soil loss

Erosion risk estimates are available for agricultural areas in Norway (The Norwegian Forest and Landscape Institute, 2006). These estimates are based on actual mapping of soil series and slopes, and the erosion risk estimate is calculated as an USLE approach assuming a standard slope length of 100m. The standard erosion risk approach has been calibrated for the climate at Romerike. Water way erosion is not included in the USLE approach. It has been shown that the particle loss estimates derived from the erosion risk maps tend to be low compared to measured particle loss in the Skuterud catchment (Lundekvam, 2004). In the newly developed erosion index this has been solved by multiplying the erosion risk map estimates by a factor of 1.8 (Bechmann et al., 2007). Further, the influence of soil management is taken into accont by multiplying the particle loss by factors (Table 6) given by Lundekvam (2002). The erosion index is provided as field estimates instead of estimates for soil map units as in the erosion risk map.

Table 6. Factors for reduction in erosion risk caused by soil management different from autumn ploughing (Lundekvam, 2002)

Soil management	Autumn ploughing	Winter wheat	Autumn harrowed	Stubble	Catch crop	Pasture
Factor	1.0	1.0	0.5	0.15	0.1	0.05

With this procedure, particle loss estimates varied from 70 to 2320 kg ha^{-1} between fields in the Skuterud catchment (Figure 10 A), with an average of 570 kg ha^{-1}. Accordingly, multiplying this particle loss estimate by the soil nitrogen content in section 3.2.1., yielded amounts of particulate N of 0.1 to 3.5 kg ha^{-1} (Figure 10 B).

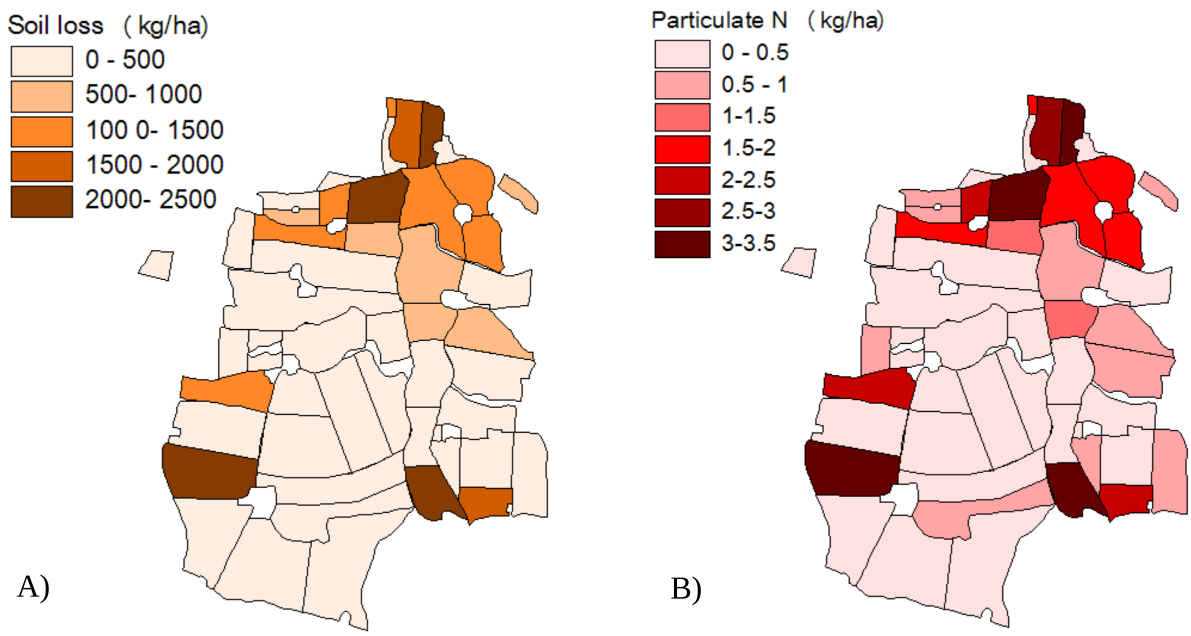

Figure 10. A) Estimated soil loss (from erosion index), and B) estimated particulate nitrogen.

3.3 Incidental nitrogen loss from manure

"Incidental N loss" refers to the release and transport of nitrogen from manure by surface runoff events. For simplicity, it was not distinguished between incidental and leaching losses of dissolved nitrogen from manure. The whole source of dissolved nitrogen was therefore included in the "Dissolved N" part of the N-index (Table 2). The organic nitrogen, on the other hand, was split in two – one part contributing to the following years' source of dissolved nitrogen, the other part separated as incidental nitrogen loss. It was assumed that only manure applied in autumn would be at risk for incidental loss, considering the risk of precipitation and surface runoff. Winter was not included, since it is, by law, illegal to apply manure on frozen or snow covered ground. Further, all organic nitrogen applied in autumn would be available for incidental loss if surface runoff should occur. The risk of surface runoff was assumed to increase from early to late autumn, and the amount of incidental loss of organic nitrogen was therefore set to 0.3 × org N, 0.2 × org N and 0.05 × org N for late, intermediate and early autumn respectively (the same date limits as for tillage timing was used). The factors 0.3, 0.2 and 0.05 (corresponding to 30, 20 and 5 % risk for incidental loss) were guesstimates. It remains to find better documented figures, both for the partitioning of precipitation on surface and subsurface runoff and the temporal change in likelihood of rainstorm events leading to significant runoff and drainage events.

The remaining org N was transferred to the following years pool of org N, made available in the "Dissolved N" part of the N-index. The equation is shown in Table 7.

Table 7. Calculation of incidental organic N loss from manure.

Incidental N loss				
Incidental N	Manure amount × org N × application timing risk factor			
Application timing risk factor	0 Spring/summer	0.05 Early autumn	0.2 mid-autumn	0.3 Late autumn

3.4 Retention of dissolved and particulate N

Studies of residence time and recession characteristics carried out in the Skuterud catchment have indicated low retention of dissolved nitrogen in this catchment (Deelstra, pers comm.). The low importance of retention in this study may be related to the scale of the study. The retention factor may be more relevant at larger scales. The retention of particulate nitrogen has not yet been included in the N-index, though it may contribute to reduced transfer of particulate nitrogen. Its inclusion will awaits a procedure for estimating particle sedimentation/retention in the erosion index. As a consequence, N retention was set to 0.

4. Calculated nitrogen index for the Skuterud catchment

4.1 Mean nitrogen index for the agrohydrological years 1994-95 to 2002-03

The calculated area-weighted mean N-index for the Skuterud catchment was 39 kg ha^{-1} over the agrohydrological years 1994-95 to 2002-03. The measured nitrogen loss from the catchment was 45 kg ha^{-1} in mean for 1994-95 to 2002-03. The field specific mean N-indices are shown in Figure 11, and varied from 8 to 94 kg ha^{-1} in this period. The N-index was commonly highest on fields with low clay content, where cereals have been grown and manure has been applied. The lowest N-indices were found on fields with high clay content and ley. This indicates that the N-index captures the most important management effects on nitrogen loss reasonably well, at least over several years. For individual years and individual fields the N-index varied from -93 to 214 kg ha^{-1}. The reason for the negative values is simply that some fields have received less nitrogen input than what has been removed, resulting in a negative balance.

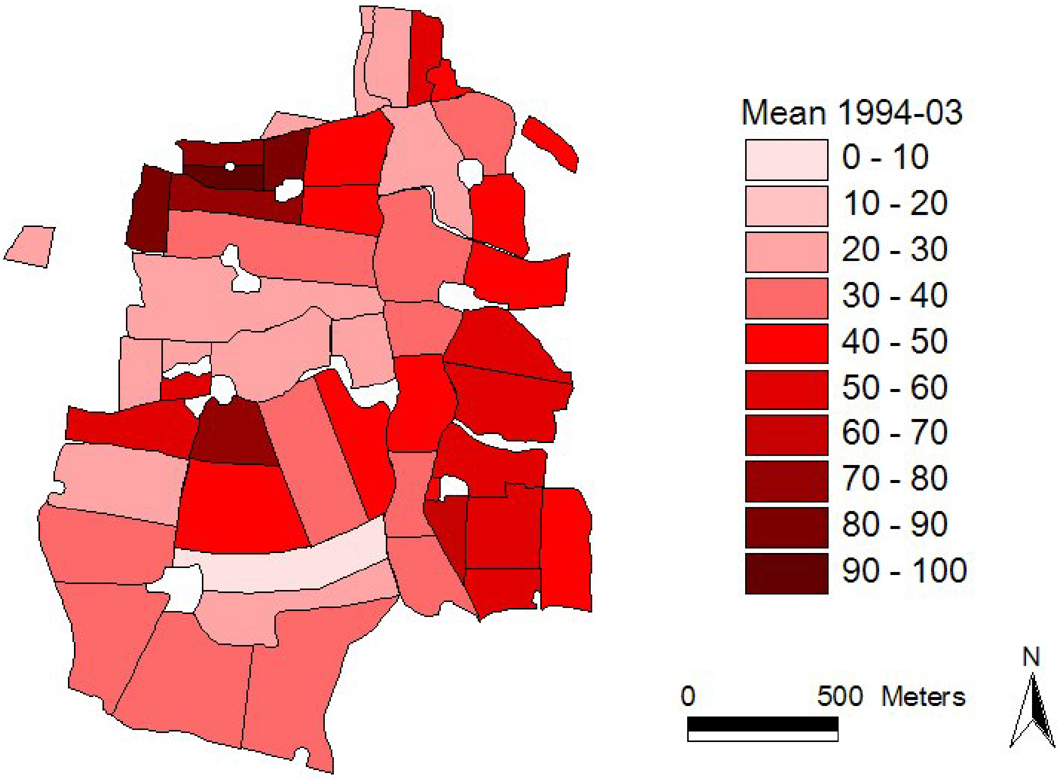

Figure 11. N-index at the field scale for the Skuterud catchment. Field averages for the period 1994-95 to 2002-03 (1994-2002 in legend).

4.2 Management scenarios for the year 2001

Different management scenarios were tested for the year 2001:

- **Catch crops** following all spring crops when the spring crop is not followed by a winter crop or ley
- All fields in **stubble**
- All fields **ploughed in autumn**
- **Norm fertilisation** instead of actual fertiliser level. The norm fertiliser level is supposed to correspond to the crop demand. It was calculated according to Table 8, as follows:

Norm fertilisation = Norm N + Adjustment N × (Expected yield – Norm yield) – (manure org N × 0.2 + manure org N PY + manure inorg N)

Table 8. Norm yields, norm N levels corresponding to norm yield and amount of N to add/subtract relative to difference between expected and norm yields (adjustment N). Figures are from Fystro et al. (2006).

Crop	Norm yield (kg ha^{-1})	Norm N (kg ha^{-1})	Adjustment N (kg $(kg\ ha^{-1})^{-1}$)
Barley	4000	95	0.16
Oats	4500	93	0.16
Spring wheat	4500	113	0.16
Winter wheat	5500	129	0.16
Winter rye	4500	113	0.16
Spring canola	2000	120	0.3
Ley	7000	220	0.2

The reference state to which the scenarios were compared, was the actual management on all fields in the Skuterud catchment in 2001, but with crop yields modified so that expected yields were used instead of the recorded yields. Expected yields were obtained by using the mean yield for the period 1994-2003 for each crop. Crop distributions and tillage in 2001 are shown in Figure 12 and Figure 13. Input data and results are listed in the tables in Appendix 1.

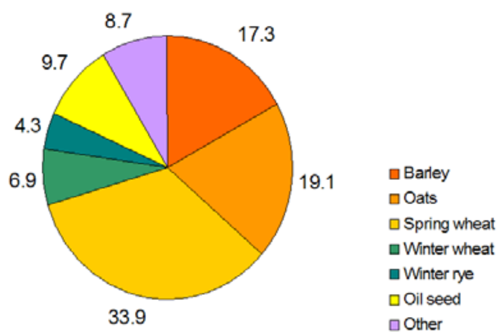

Figure 12. Crop distribution (% of agricultural land) in the Skuterud catchment, 2001.

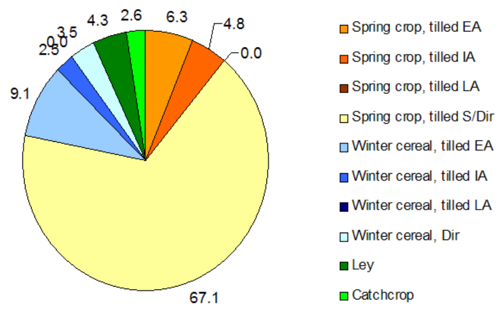

Figure 13. Tillage and autumn crop cover (% of agricultural land) in the Skuterud catchment, 2001. S = spring, Dir = direct drilling, EA = early autumn, IA = intermediate autumn, LA = late autumn.

The norm fertilisation scenario was the most efficient in reducing the N-index from 45 to 14 (Table 9), as many fields were fertilised in excess of the crop demand in 2001. Growing catch crops was also quite efficient. Putting all fields in stubble had minor effects, as most fields were in stubble in 2001. Autumn ploughing the entire area resulted in a small increase in the N-index. Calculated N-indices for individual fields are shown in Figure 14.

Table 9. Area weighted N-index for the Skuterud catchment in 2001 (actual management - reference) and for 4 scenarios.

Reference	Catch crop	Norm fertilisation	Stubble	Autumn ploughing
45	34	14	44	49

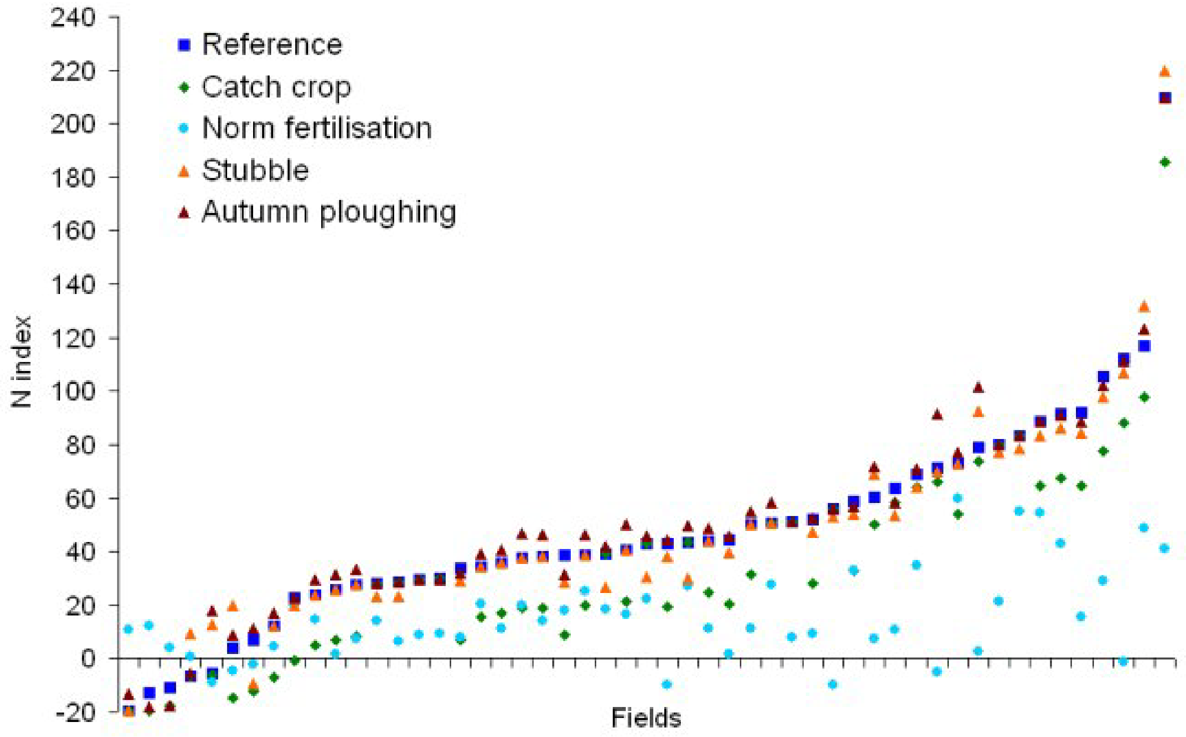

Figure 14. N indices for fields in the Skuterud catchment, for actual management in 2001 (reference) and for four scenarios.

5. Conclusions

The nitrogen index (N-index) is an alternative risk assessment tool to the more advanced process-based models. The present work showed the potential of the N-index to be able to pick up significant differences in risk of N loss and potential of the N index as a management tool focusing on measures which may be used in practice to reduce N losses. There is, however, still work to be done to be able to represent processes contributing to N losses. The work on the N-index illuminated the need for links between the factors representing processes contributing to risk of N loss and the information available at the field scale for farmers. The improvements for the N-index include:

- Effect of precipitation and temperature
- Yield-response functions
- Yield N-content
- Denitrification – effect of manure, drainage, temperature and precipitation
- N-fixation in soil and plant
- Organic soil
- Incidental N-losses

Future work with the N index include calibration and validation of the N index outside the area for which it was developed, the Skuterud catchment. The final aim of the N index is to be included in the nutrient management plan for farmers.

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7. Appendix

Oversikt over vedlegg

Nr	Emne
1	Nitrogen index and input data for management scenarios in the Skuterud catchment, 2001.

Input: manure (TY = this year, PY = previous year)

Field ID	Manure	Timing	Amount (tons ha^{-1})	Incorporation (hours)	inorg N (kg ha^{-1})	org N TY (kg ha^{-1})	org N PY (kg ha^{-1})
0101							
0102							
0301							
0302							
0303							
0304							
0305							
0306							
0307							
0401							
0402							
0403							
0501	Cattle, solid	Spring	40	24	16	79	
0502	Cattle, solid	Summer	40	Not inc.	16	79	46
0503							
0504							
0505							
0506							
0507							
0508							
0509	Cattle, solid	Spring	40	24	16	79	40
0510						26	26
0601							
0602							
0603							
0604							
0605							
0606							
0607							
0901							
0902							
0903							
0904							
0905							
0906							
0907							
0908							
0909							
1001							
1002							
1003							
1004							
1005							
1101							
1102							
1103							
1104							
1201							
1202							
1203							
1204							

Input: deposition, fertiliser, winter crop and tillage (PY = previous year, A = autumn, S/ N spring/ no till)

Field ID	Deposition (kg ha^{-1})	Fertiliser (kg ha^{-1})	Winter crop PY	Winter crop N PY (kg ha^{-1})	Tillage timing	Tillage N (kg ha^{-1})
0101	5.4	105	Winter wheat	15	S/ N	0
0102	5.4	105	Catch crop	25	Mid. A	3
0301	5.4	168		0	S/ N	0
0302	5.4	190	Winter wheat	15	Mid. A	3
0303	5.4	190	Winter wheat	15	Mid A	3
0304	5.4	160	Winter wheat	15	Early A	5
0305	5.4	160		0	Early A	5
0306	5.4	190		0	S/ N	0
0307	5.4	190		0	S/ N	0
0401	5.4	105	Winter wheat	15	S/ N	0
0402	5.4	200	Ley	20	S/ N	0
0403	5.4	167		0	S/ N	0
0501	5.4	98	Winter wheat	15	Early A	5
0502	5.4	98		0	S/ N	0
0503	5.4	200	Ley	20	S/ N	0
0504	5.4	200	Ley	20	S/ N	0
0505	5.4	223	Ley	20	S/ N	0
0506	5.4	200	Ley	20	S/ N	0
0507	5.4	111	Winter wheat	15	S/ N	0
0508	5.4	111		0	S/ N	0
0509	5.4	201		0	S/ N	0
0510	5.4	201		0	S/ N	0
0601	5.4	153	Winter wheat	15	S/ N	0
0602	5.4	126		0	Early A	5
0603	5.4	153	Winter wheat	15	S/ N	0
0604	5.4	126		0	S/ N	0
0605	5.4	157		0	S/ N	0
0606	5.4	157		0	S/ N	0
0607	5.4	126		0	S/ N	0
0901	5.4	158		0	S/ N	0
0902	5.4	151		0	S/ N	0
0903	5.4	128		0	Early A	5
0904	5.4	128		0	S/ N	0
0905	5.4	143		0	S/ N	0
0906	5.4	137		0	S/ N	0
0907	5.4	128	Winter rye	15	Early A	5
0908	5.4	122		0	S/ N	0
0909	5.4	116	Winter rye	15	S/ N	0
1001	5.4	137		0	S/ N	0
1002	5.4	105		0	S/ N	0
1003	5.4	126	Winter wheat	15	S/ N	0
1004	5.4	126	Winter wheat	15	S/ N	0
1005	5.4	137	Winter wheat	15	S/ N	0
1101	5.4	116		0	Early A	5
1102	5.4	105		0	Mid. A	3
1103	5.4	124		0	Early A	5
1104	5.4	118	Winter wheat	15	Early A	5
1201	5.4	172		0	Mid. A	3
1202	5.4	168		0	Mid. A	3
1203	5.4	126		0	S/ N	0
1204	5.4	130		0	S/ N	0

Output: Crop (w/CC = with catch crop), yield N, split application N, wintercrop N, straw N.

Field ID	Crop	Expected yield (kg ha^{-1})	Yield N (kg ha^{-1})	Split application N (kg ha^{-1})	Winter crop N (kg ha^{-1})	Straw N (kg ha^{-1})
0101	Oats w/CC	5060	89		19	
0102	Oats	5060	89			
0301	Spring canola	2130	72	5		
0302	Spring wheat	4850	97	5		
0303	Spring wheat	4850	97	5		
0304	Barley	5070	89	5	11	
0305	Barley w/CC	5070	89	5	19	
0306	Spring wheat w/CC	4850	97	5	19	
0307	Spring wheat w/CC	4850	97	5	19	
0401	Barley	5070	89		15	16
0402	Ley	4960	159			
0403	Spring wheat	4850	97	5		15
0501	Barley	5070	89		11	16
0502	Spring wheat	4850	97			15
0503	Ley	4960	159		15	
0504	Ley	4960	159		15	
0505	Ley	4960	159		15	
0506	Ley	4960	159			
0507	Oats	5060	89			16
0508	Oats	5060	89			
0509	Spring wheat	4850	97	5		15
0510	Spring wheat	4850	97	5		
0601	Spring canola	2130	72	5	11	
0602	Barley	5070	89		11	
0603	Spring canola	2130	72	5		
0604	Barley	5070	89			
0605	Spring wheat	4850	97	5		
0606	Spring wheat	4850	97	5		
0607	Spring wheat	4850	97			
0901	Spring wheat	4850	97			
0902	Spring wheat	4850	97			
0903	Oats	5060	89			
0904	Spring wheat	4850	97			
0905	Spring wheat	4850	97			
0906	Winter rye	4540	79			
0907	Oats	5060	89			
0908	Oats	5060	89			
0909	Oats	5060	89			
1001	Spring wheat	4850	97			
1002	Winter wheat	5890	118			
1003	Oats	5060	89			
1004	Oats	5060	89			
1005	Spring canola	2130	72			
1101	Winter wheat	5890	118	5		
1102	Winter wheat	5890	118	5		
1103	Oats	5060	89		11	
1104	Oats	5060	89	5		
1201	Winter rye	4540	79		11	
1202	Oats	5060	89		11	
1203	Oats	5060	89			
1204	Winter rye	4540	79			

Output: Soil properties, denitrification

Field ID	Clay %	SOM %	Soil N %	Denitrification (kg ha^{-1})
0101	29	3.3	0.14	20
0102	32	4.8	0.19	23
0301	15	4.9	0.20	9
0302	15	2.6	0.12	9
0303	31	3.2	0.14	22
0304	30	3.5	0.15	21
0305	10	4.1	0.17	5
0306	6	4.8	0.19	2
0307	15	3.4	0.15	9
0401	15	3.4	0.15	9
0402	27	3.5	0.15	19
0403	26	3.4	0.15	18
0501	26	4.3	0.17	18
0502	24	3.7	0.16	17
0503	25	3.9	0.16	17
0504	26	2.2	0.10	17
0505	26	3.7	0.16	18
0506	31	5.1	0.20	23
0507	27	4.1	0.17	19
0508	30	4.4	0.18	21
0509	27	4.4	0.18	19
0510	33	4.5	0.18	24
0601	25	3.9	0.16	18
0602	18	3.8	0.16	11
0603	15	5.3	0.21	9
0604	14	4.2	0.17	9
0605	20	3.6	0.15	13
0606	29	4.7	0.19	21
0607	32	4.5	0.18	23
0901	24	3.0	0.13	16
0902	24	4.1	0.17	16
0903	28	3.5	0.15	20
0904	20	3.4	0.15	13
0905	24	2.3	0.11	16
0906	19	4.0	0.16	13
0907	10	3.3	0.14	5
0908	19	3.1	0.13	12
0909	9	9.9	0.37	6
1001	14	3.8	0.16	8
1002	20	3.2	0.14	13
1003	22	4.2	0.17	15
1004	25	4.0	0.16	17
1005	14	3.4	0.15	8
1101	30	3.2	0.14	21
1102	17	3.4	0.14	10
1103	14	2.9	0.13	8
1104	20	3.4	0.15	13
1201	20	3.5	0.15	13
1202	33	3.9	0.16	23
1203	26	3.2	0.14	17
1204	20	3.4	0.15	13

N-index = Dissolved N (= Input - Output) + Particulate N + Incidental N + N retention

Field ID	Input (kg ha^{-1})	Output (kg ha^{-1})	Dissolved N (kg ha^{-1})	Particulate N (kg ha^{-1})	Incidental N (kg ha^{-1})	N retention (kg ha^{-1})	N-index (kg ha^{-1})
0101	122	128	-6	0.4	0	0	-5.8
0102	132	111	21	2.0	0	0	23
0301	173	87	86	0.3	0	0	86
0302	210	111	99	1.7	0	0	101
0303	210	124	86	1.3	0	0	87
0304	182	126	55	3.2	0	0	59
0305	170	118	53	2.3	0	0	55
0306	196	123	73	1.0	0	0	74
0307	196	130	66	0.6	0	0	66
0401	122	128	-7	0.2	0	0	-6.6
0402	220	177	43	0.2	0	0	43
0403	172	135	38	0.5	0	0	38
0501	149	134	15	2.5	0	0	17
0502	245	129	116	0.7	0	0	117
0503	220	191	30	0.2	0	0	30
0504	220	191	29	0.1	0	0	29
0505	243	192	51	0.2	0	0	51
0506	220	181	39	0.1	0	0	39
0507	127	124	4	0.4	0	0	3.9
0508	116	110	6	0.3	0	0	6.7
0509	341	136	204	0.3	0	0	205
0510	233	126	107	0.2	0	0	107
0601	170	106	64	0.4	0	0	64
0602	136	111	25	3.2	0	0	28
0603	170	87	83	0.4	0	0	84
0604	131	97	34	0.3	0	0	34
0605	162	115	47	0.4	0	0	47
0606	162	123	39	0.6	0	0	40
0607	131	120	12	0.3	0	0	12
0901	163	113	50	0.4	0	0	50
0902	157	113	43	0.3	0	0	44
0903	139	108	30	3.5	0	0	34
0904	134	110	23	0.5	0	0	24
0905	148	113	35	0.3	0	0	36
0906	142	92	50	0.8	0	0	51
0907	150	93	56	2.4	0	0	59
0908	127	100	27	0.5	0	0	27
0909	132	94	38	0.8	0	0	39
1001	142	105	37	1.0	0	0	38
1002	110	131	-20	0.6	0	0	-20
1003	143	103	39	1.2	0	0	40
1004	143	106	37	0.9	0	0	38
1005	153	81	72	0.2	0	0	73
1101	126	144	-18	1.8	0	0	-16
1102	113	133	-20	1.9	0	0	-18
1103	134	108	27	1.7	0	0	28
1104	139	107	33	1.0	0	0	34
1201	181	104	77	3.4	0	0	80
1202	176	123	53	2.8	0	0	56
1203	131	106	25	0.5	0	0	26
1204	136	93	43	0.5	0	0	44

Scenarios: N-indices (kg ha^{-1}) for reference management in 2001 and 4 scenarios.

Field ID	Reference	Catch crop	Norm fertilisation	Stubble	Autumn ploughing
0101	-5.8	-5.9	-8.8	-5.8	-0.6
0102	23	-0.8	20	20	23
0301	86	68	43	86	91
0302	101	77	29	98	102
0303	87	64	16	84	88
0304	59	59	11	54	59
0305	55	50	7.2	50	55
0306	74	74	2.4	74	83
0307	66	66	-5.2	66	73
0401	-6.6	-6.7	0.5	-6.6	-5.4
0402	43	43	22	43	46
0403	38	19	-10	38	44
0501	17	17	-11	12	17
0502	117	98	49	117	123
0503	30	30	9.2	30	30
0504	29	29	8.8	29	29
0505	51	51	7.9	51	51
0506	39	39	18	39	42
0507	3.9	-15	-4.8	3.9	9.0
0508	6.7	-12	-2.0	6.7	11
0509	205	186	41	205	210
0510	107	88	-1.4	107	111
0601	64	64	35	64	69
0602	28	28	14	23	28
0603	84	65	54	84	89
0604	34	15	20	34	39
0605	47	28	9.2	47	53
0606	40	21	1.5	40	46
0607	12	-6.8	4.6	12	17
0901	50	31	11	50	55
0902	44	25	11	44	49
0903	34	7.0	7.7	29	34
0904	24	5.0	14	24	30
0905	36	17	11	36	40
0906	51	51	28	51	58
0907	59	33	33	54	59
0908	27	8.5	7.5	27	33
0909	39	20	25	39	46
1001	38	19	20	38	47
1002	-20	-20	11	-20	-13
1003	40	21	16	40	50
1004	38	19	14	38	46
1005	73	54	60	73	77
1101	-16	-17	3.9	-21	-16
1102	-18	-19	12	-21	-18
1103	28	28	6.5	23	28
1104	34	9.0	18	29	34
1201	80	80	22	77	80
1202	56	56	-10	53	56
1203	26	7.0	1.8	26	32
1204	44	44	27	44	50
Catchment	45	34	14	44	49