LINKING FARM MANAGEMENT TO AGRI-ENVIRONMENTAL INDICATORS: RECENT EXPERIENCES FROM THE NETHERLANDS

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Abstract

Agriculture in industrialised countries is under increasing pressure. Trade liberalisation, increasingly stringent environmental policy and climate change provide both a threat and a challenge to farmers and agricultural research. The Netherlands has a tradition of intensive agricultural research and extension projects. Recent systems oriented, interactive and dynamic research projects were extremely data intensive, involving time-consuming monitoring programmes. As such monitoring programmes are costly, alternatives are pursued. Agri-Environmental Indicators (AEIs) were used in communication between researchers, farmers, extension officers and policy makers. General requirements for AEIs are that they should (i) refer to relevant policy issues, (ii) be based on sound science (recognising that their development is an evolving process), (iii) be quantifiable, (iv) be relevant for target groups involved, (v) be easy to interprete, (vi) be cost effective, and (vii) be able to facilitate communication

In this paper we evaluate experiences of AEI use in Dutch research projects, presenting applications predominantly in nitrogen management, but also in carbon and water management. The paper lists applications in both dairy and arable farming. AEIs, especially farm nitrogen budgets, appeared excellent instruments for communication. AEIs should however be applied with care, as they simplify spatially and temporally highly variable processes. The use of nitrogen budgets to compare operational management of different groups of farmers only is valid if these groups are homogeneous with respect to their activities and internal flows. As a rule, the scale at which AEIs can be safely applied should reflect the temporal and spatial variability of the relevant soil processes. Application at too large a scale will easily lead to neglect of the possible large variations and – hence – emissions taking place. AEIs should further be applied in integrated farm management evaluation. Application to a limited aspect of farming, e.g. nitrogen or water management, easily leads to the neglect of less favourable effects in other aspects. As processes determining the nutrient, water, and carbon cycles are highly interacting, management of either should also consider management of the other compounds.

Introduction

The agricultural sector in Europe is restructuring in response to changes in demand from society. So far, however, the track record of agricultural development is not encouraging. Agriculture has provided many examples of unforeseen effects on the environment including the pollution of soil and water resources as result of high inputs of fertilizers and pesticides. The challenge facing agriculture is to make the transition to more sustainable forms of land use. Trade liberalisation, increasingly stringent environmental policy and climate change are only a few factors that shape the environment under which the transition has to take place.

In this paper we analyse the impact of agricultural land use on the biophysical environment, notably through its use of nitrogen, carbon and water. We focus on farm management and the use of agri-environmental indicators (AEIs) to guide and evaluate farm management. The farm, an enterprise that uses resources to produce goods and services, is the entity for which management decisions are made. In this respect, a farm has no fixed spatial dimension; it can comprise a few hectares up to several square kilometres.

Indicators

We define AEIs as derived simplified concepts that describe the relationship between a farm and its environment. Indicators are, in essence, vehicles for communication (OECD, 2001), that can help to provide information (decision makers, general public) about trends related to agriculture and land use. AEIs play a crucial role in the development and evaluation of policies. OECD work on AEIs focuses on (i) the relation between agriculture and its broader context, be it economic, social or environmental; (ii) the relation between farming activities and the impact of farming on the environment; (iii) trends in the use of farm inputs and natural resources, and (iv) environmental impact of agriculture (OECD, 2004).

Over time, different types of indicators have been developed. Indicators referring to land use changes (see e.g. JRC/IES/Eurostat, 2002) use satellite image and remote sensing data, thus refering to changes in land cover and associated land use rather than dynamics of water, energy or nutrients in crop or animal production at farm level. Ghersa *et al*. (2002) calculated indicators for landscape management and farm sustainability using landscape and farm data. Indicators referring to soil microbial activity (as a measure for soil quality) are discussed by Schloter *et al*. (2003). Although related to nutrient management, microbial indicators (e.g. microbial biomass, microbial activity, nitrogen release from mineralisation) lack a direct relation to fertilization or nutrient availability for the crop. Hence, their use in discussions with farmers and/or policy makers is limited.

Current environmental problems related to agriculture include high application levels and limited efficiency of input use (nitrogen, phosphorus, energy, water), leading to negative external effects (high nutrient emissions contributing to acidification, eutrophication, global warming and groundwater depletion). Table 1 lists AEIs that have been suggested for the monitoring and evaluation of nitrogen, carbon/energy and water management in agriculture. There is a limited number of studies that is discussing pros and cons of such AEIs. According to Langeveld *et al.* (2002a), indicators (as compared to nitrate measurements) are cheaper and (as they are more easily translated in day-to-day farmer decision-making) more practical instruments in discussions with farmers concerning evaluation of their fertilisation practices.

Schröder *et al*. (2003) discuss common nitrogen AEIs. Whole-farm nitrogen balances can be used to generate awareness among farmers and stimulate re-examination of routine practices, but they remain too coarse for fine-tuning of nitrogen management, requiring additional information from sub-farm compartments (budgets at soil, crop, manure or livestock level; see Figure 1). This is especially the case in dairy farming (Aarts *et al.*, 2000), where farm management includes both crop and animal production. Van der Werf and Petit (2002), analysing twelve indicators-based methods for evaluation of agricultural practice, conclude that indicators preferably should (i) be based on farm practices rather than on environmental effects, (ii) be expressed as values rather than scores (per unit of surface as well as per unit of production), (iii) be science-based.

Indicators for water policy evaluation, discussed by Zalidis *et al.* (2004), should (i) correlate to inputs and outputs of land use activities, (ii) be sensitive to changes in climate and agricultural management practices, (iii) integrate physical, chemical and biological properties and processes, (iv) be easy to use under field conditions, (v) be cost effective, (vi) be easy to interprete and, finally, (vii) be policy relevant. No doubt, more requirements can be listed. Without claiming to be complete, we conclude that AEIs preferably should (i) refer to relevant policy issues, (ii) be based on sound science (recognising that their development is an evolving process), (iii) be quantifiable, (iv) be relevant for target groups involved, (v) be easy to interprete, (vi) be cost effective, and (vii) be able to facilitate communication (adapted and modified from Schröder *et al*., 2004; OECD, 2001; OECD, 2002; Langeveld *et al.* 2002a; Zalidis *et al.*, 2004).

Table 1 AEIs for nitrogen, carbon and water management at field and farm level.

AEI	Definition	Target group(s)
Nitrogen		
Nitrogen surplus	Difference between nitrogen input and output.	Policy makers and farmers
Nitrogen Use Efficiency	Ratio of nitrogen output to nitrogen input.	Farmers and researchers
Residual Soil Mineral Nitrogen	Amount of mineral nitrogen found in the soil profile at harvest or in autumn.	Farmers and researchers
Nitrate concentration of groundwater	Nitrate measured in groundwater.	Policy makers
Carbon		
Organic matter budget	Calculated and measured changes in soil organic matter.	Policy makers, farmers and researchers
Energy Consumption	Consumption of mineral fuels, both direct (fuel consumption at farm) and indirect (for transportation to farm and inputs: fertilisers, chemicals, machinery).	Policy makers and researchers
Greenhouse Gas Emission	Calculated and measured emissions of Greenhouse Gases (CO_2, N_2O, CH_4).	Policy makers and researchers
Water		
Water use efficiency	Ratio of water input to unit product	Policy makers, farmers and researchers

In the Netherlands, AEIs are used to facilitate communication between policy makers, farmers and scientists. Consequently, different indicators may target different groups and target different goals. Thus, in the communication between scientists, policy makers, consultants and farmers, different preferences may exist as to which indicators are to be used. Basically, however, indicators that are not accepted by any major group of actors only have limited value. Experiences with AEIs in the Netherlands focus on the process of evaluating and redesigning farming systems, addressing issues in relation to economic returns and environmental impact. In this paper, we discuss indicators related to production and environmental impact. First, we introduce our research approach. Next, two case studies are presented, after which we discuss feedbacks between different processes related to nitrogen, carbon and water management at farm level. The paper ends with a discussion and some conclusions.

Approach

The Agrosystems Research group, part of Plant Research International (Wageningen University and Research Centre), designs effective farming practices that enable realisation of both production and environmental goals, and assists farmers and land managers in the adoption of such practices. Although traditionally focussing on intensification and expansion, research has been re-oriented towards environmental issues, often combining input reductions with technological innovations, thus contributing to realisation of both objectives. Crucial in the approach is the use of conceptual models and indicators.

A farm system is modelled using a simple flow diagram (Schröder *et al*., 2003; Corré *et al.* 2003). Several compartments are distinguished, i.e., soil, crop, feed, animal and manure; inputs and outputs are designated to the relevant compartment (Figure 1).

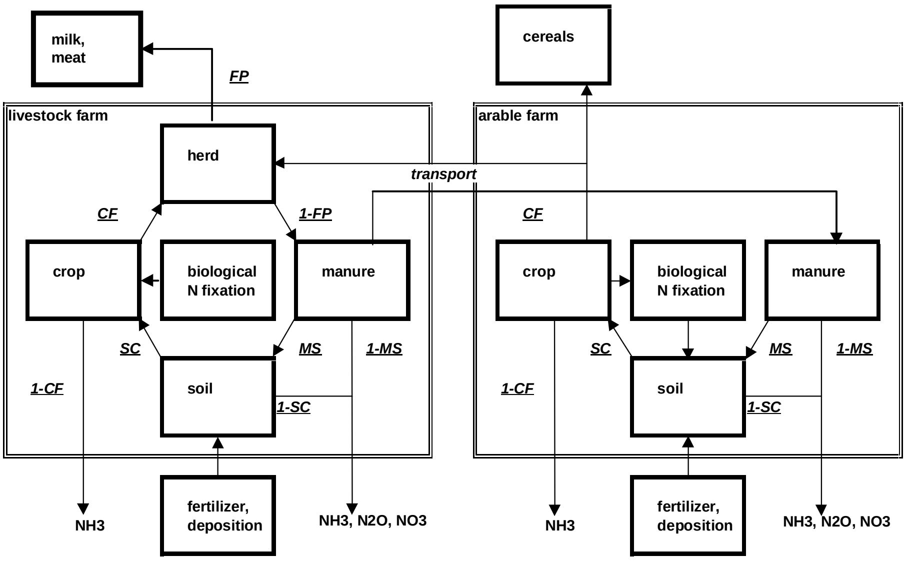

Figure 1. Example of the mixed farm diagram of the model 'N-FarmFlow' (full explanation of figure in: Schröder *et al*., 2003; Corré *et al*., 2003)

The core of the model is the in-output relationship, allowing the definition of indicators not only for individual compartments, but also for the whole farm system or even a combination of farms. Indicators make use of compartments and their relationships (Figure 2). A simple indicator can be the input level, the size of the compartment, or the output level or a combination of these. More complex indicators may combine part of the system to a single value, integrating several aspects of the system or the entire system.

Underlying selection and quantification of the indicators is the understanding of the interaction between the various compartments. Complex dynamic simulation modes can be used to determine the in-output relationships for the various compartments, allowing a detailed analysis including non-linear effects and trade-offs. In most cases data availability and quality dictate the level of detail. At the most detailed level, soil-crop processes can be modelled (e.g., by using CNGRAS (Conijn and Henstra, 2003), PlantSys (Yin *et al.*, 2001) or Farmmin (Van Evert *et al.*, 2003)). At higher scales, modelling can refer to farm level activities (Vleeshouwers and Verhagen, 2001), identifying the role of farm management in the steering of the system.

By using this approach the effectiveness of farm activities on nitrogen losses (Schröder et al., 2003; Conijn and Henstra, 2003), carbon sequestration (Vleeshouwers and Verhagen, 2001), energy (Corré *et al*., 2003) and water use has been evaluated. The approach can be used to compare the effectiveness of farm activities and (re)design alternative farming systems.

The development, testing and dissemination of more sustainable farming practices is done in four phases (Vereijken, 1997). First, a new, desirable, farming system is designed using a set of quantified and prioritised objectives. Next, the system is implemented and adapted at an experimental farm, after which it is applied and further adjusted on a series of pilot farms (commercial farms linked to the experimental farm that replace standarised, controlled agro-ecological and socio-economic conditions by real world situations). The last phase comprises dissemination to other commercial farms. Models play an important role in the first two phases, but are more or less absent in the latter two. Indicators play a role in all phases. Their importance tends to increase with each phase.

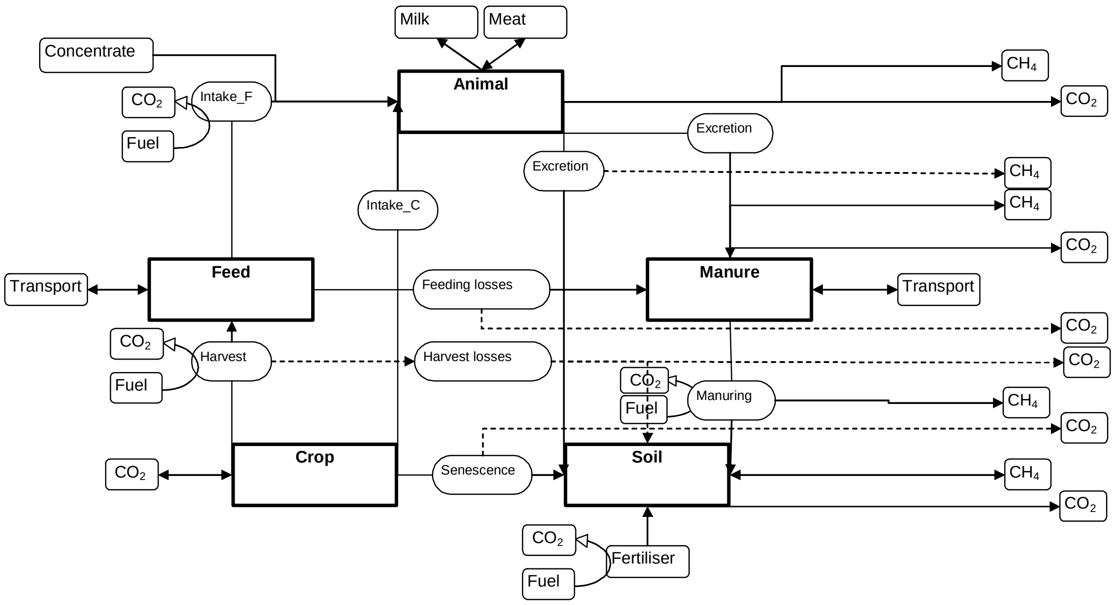

Figure 2. Example of a complex carbon flow diagram of a livestock system (full explanation in: Schils *et al*., in press)

The approach has been applied to two large research projects in the Netherlands that design, test and implement sustainable systems for dairy farming and for the production of field crops. Innovative and possible economic risky farming systems that meet the most stringent environmental goals are developed on experimental farms. On the pilot farms, farmer, extension service and scientists each year jointly develop a farming plan that aims at meeting the environmental goals, making use of promising measures derived from the results obtained at the experimental farms. The projects 'De Marke' (Aarts *et al*., 1992, 1999) and 'Cows and Opportunities' on dairy farming (Oenema *et al*., 2001) and 'Farming with a Future' on field crops (Neeteson *et al*., 2001; Langeveld, 2003) applied AEIs in the process of developing, testing and evaluating new farm systems, facilitating communication between farmers, policy makers and scientists of many disciplines. So far, the major focus in the projects has been on nutrient management, with emphasis on nitrogen and phosphorus. Recently, however, AEIs have been applied in carbon and water management. Below we present some case studies focussing on the nitrogen cycle.

Case studies

'De Marke' (experimental dairy farm)

The experimental dairy farm 'De Marke' is located on a dry sandy soil in the Eastern part of the Netherlands. It has a milk production intensity of 11,900 kg/ha, which is about the countries' average. In 1993 a management strategy as the best way to reduce nutrient losses on dairy farms, developed on the basis of model calculations (Aarts *et al*., 1992), was implemented to investigate its technical potentials during a number of years. The main features of the strategy are that

- nitrogen throughput is minimised by using low-nitrogen feed and reduced fertiliser application,
- the share of grassland in total crop area is kept smaller in comparison to that on conventional farms, and consequently the area of forage maize larger,
- grazing of lactating cows is restricted to eight hours per day while cows in autumn are stabled a month earlier than is common practice.

As a result of the management strategy the farm nitrogen surplus (nitrogen inputs to the farm minus nitrogen outputs from the farm) decreased to such an extent that after a number of years acceptable levels of nitrate leaching were reached and the EU norm of 50 mg nitrate per litre groundwater was met (Figure 3).

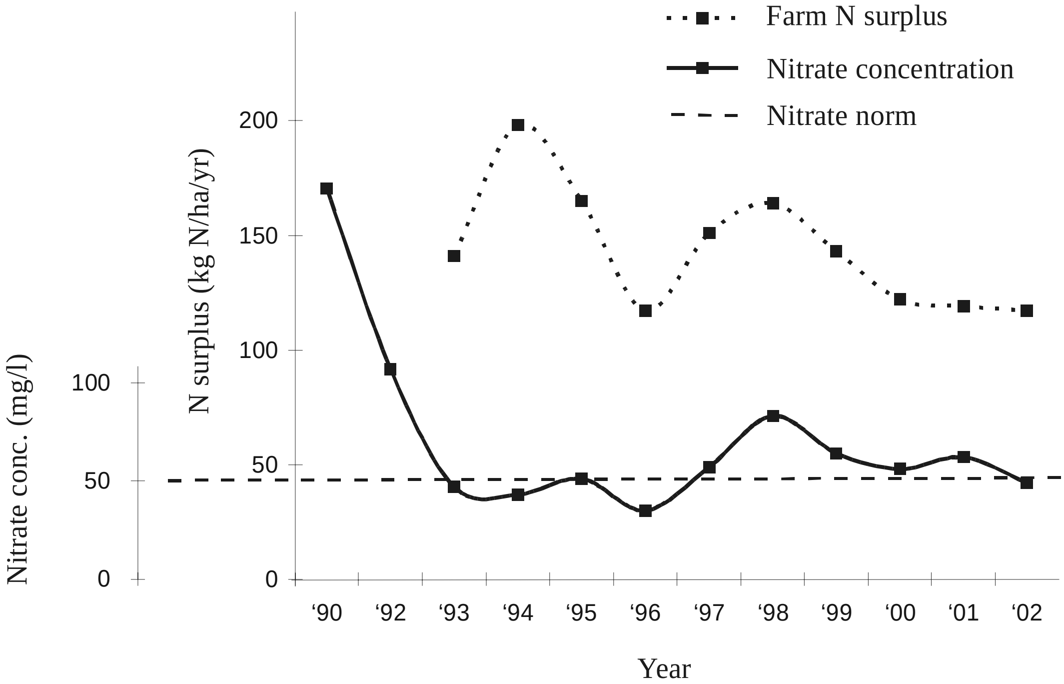

Figure 3. The course of the farm nitrogen surplus and the nitrate concentration in the groundwater (as compared to the EU Nitrate Directive norm) at the experimental dairy farm "De Marke".

Source: based on data from Aarts *et al.* (1999) and Hilhorst *et al.* (2001).

'Cows and Opportunities' (17 commercial dairy farms)

Since the "De Marke" strategy yielded promising results, in 1998 it was introduced on the 17 commercial pilot farms of 'Cows and Opportunities' to test its practical value. At the start of the project the pilot farms produced more milk[1] (48%), had more land (36%) and produced more milk per ha (15%) than average Dutch dairy farms. They were considered to be front runners. During the project period, the farms increased both in size and intensity while milk production per cow increased. The distance between pilot farms and conventional farms increased further as pilot farmers were able to exploit knowledge availability (provided by research and advisory service, but also by other pilot farmers) to enhance their professional skills.

The average farm nitrogen surplus on pilot farms decreased by more than 30% in the first five years of the project as a result of drastic decrease in the amount of mineral fertilisers applied (Table 1). Lower purchases of feeds and fertilisers improved the economic performance of the pilot farms. On the most intensive farms savings reached € 0.005 per kg milk (i.e., € 3000 per farm). Additional expenditures related to measures taken to reduce surpluses appeared to be almost negligible, but farmers had to spend more time on the planning of fertiliser use and diet composition and on recording and analysing farm data.

[1] Milk production in the Netherlands is restricted by a system of quota. Pilot farms had larger quota than the average dairy farm.

Table 1. Average major nitrogen inputs and farm nitrogen surplus at the 17 pilot farms in 1998 and 2002.

	1998	2002	Difference
N input (kg N/ha) through			
- mineral fertilisers	180	85	-95
- purchased feed	160	150	-10
Total (kg N/ha)	340	235	-105
N output (kg N/ha) [1]	74	54	-20
Farm N surplus (kg N/ha)	266	181	-85

[1] Differences in N output are mainly explained by changes in manure stocks that occurred in 1998

Source**:** Adjusted from Aarts (2003).

The farm nitrogen surplus in a specific year was a good indicator of the nitrate concentration in the groundwater in the following year (R^2 = 0.53; Figure 4). The *soil* nitrogen surplus however, calculated as the farm nitrogen surplus minus nitrogen losses through ammonia volatilisation, appeared to be a better indicator (R^2 = 0.69). Correcting the soil surplus for other non-nitrate-leaching losses (nitrogen losses through denitrification and volatilisation of nitrous oxide) is expected to yield an even better relationship with the nitrate concentration in groundwater.

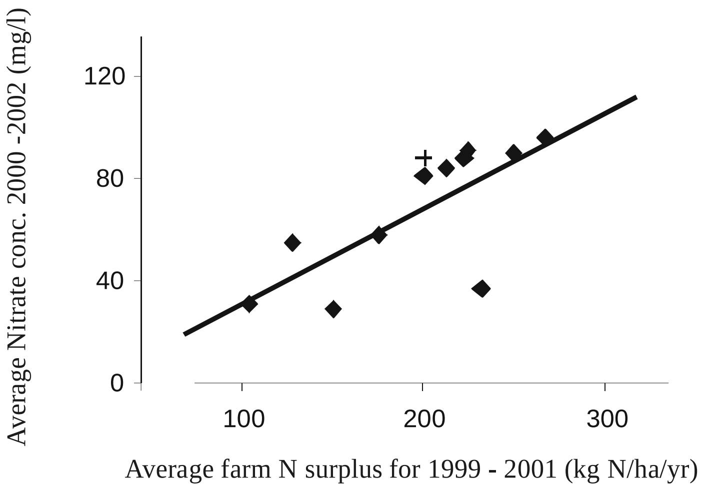

Figure 4. The relationship between the average farm nitrogen surplus in 1999-2001 and the average nitrate concentration in the groundwater in 2000-2002 at pilot farms of 'Cows and Opportunities' (R^2 = 0.54).

Source: Oenema *et al.* (in prep.)

'Farming with a Future' (4 experimental and 33 commercial arable farms)

The project 'Farming with a future', operational since 2000, has features of 'De Marke' and 'Cows and Opportunities'. It links pilot farmers with process oriented research (e.g. on nitrogen mineralisation and denitrification) and systems research on experimental farms. 'Farming with a Future' includes arable, field vegetable, tree and bulb farming, each sector being represented by an experimental farm (thus 4) and a number of commercial pilot farms (in total 33). The project aims to design, implement and improve sustainable farming systems, and to communicate the results to farmers and other actors in the agricultural sector and society (Booij *et al*., 2001; Neeteson *et al*., 2001).

'Farming with a future' assists commercial pilot farmers in the development of environmentally friendly cultivation practices. Based on an analysis of practices prior to the start of the project, recommendations on fertiliser practices were identified and discussed with the farmers. Throughout the project, farmers received support and advice. Communication and analysis were supported by measurements of mineral soil nitrogen levels throughout the growing season, after harvest and at the beginning of November as well as measurements of ground- and surface water quality (Booij *et al*., 2001; Langeveld *et al*., 2002b).

The relationship between nitrogen management, farm nitrogen surplus, soil mineral nitrogen in autumn (residual soil mineral nitrogen) and nitrate concentration in the groundwater was investigated in a case study on potato cultivation at four pilot farms on sandy soils in the South East of the Netherlands (Langeveld *et al*., 2002b). The nitrogen surpluses (on three farms) and residual soil mineral nitrogen (on all farms) exceeded the project targets (Table 2). This is partly due to the cultivation of crops which required large amounts of nitrogen application, while other crops were not able to efficiently use the nitrogen applied. Although there was relatively little difference in the amounts of residual soil mineral nitrogen and the nitrogen surpluses, large differences among the farms were observed in nitrate concentrations in the groundwater. It is not clear what factor or process is responsible for this effect. In theory, observed differences in the level of the groundwater table (which was exceptionally low at Farm 1 and exceptionally high at Farm 3) may cause differences in denitrification of soil nitrate and, hence, the amount of soil nitrate available for nitrate leaching. This could not be checked, as denitrification measurements are limited to experimental farms and no measurements were done on pilot farms.

Table 2. Farm nitrogen surplus, residual soil mineral nitrogen and nitrate concentrations in groundwater on four arable pilot farms with potatoes.

Farm no.	Farm nitrogen surplus (kg N/ha)	Residual soil mineral nitrogen (farm average; 0-90 cm soil layer) in autumn 2001 (kg N/ha)	Nitrate concentration in the groundwater in spring 2002 (farm average; mg NO_3/l)
1	86	84	146
2	136	86	89
3	140	77	45
4	168	75	146
Objective	**90**	**45**	**50**

Source: Langeveld *et al*., 2002b.

Relations between individual AEIs

Figure 4 depicts the relation between farm nitrogen surplus in one year and nitrate concentrations in the following year on commercial dairy farms. Deriving such a relation or deriving the relation between different AEIs may be very informative. Large differences exist with respect to the way nitrogen indicators can be used to predict groundwater quality (nitrate concentrations), but it is beyond the scope of this paper to discuss this in detail. More information on the relationship between nitrate groundwater concentration and common AEIs (including whole-farm nitrogen budget and residual soil mineral nitrogen) is given in Ten Berge (2002) and De Ruijter and Smit (2003).

Trade-offs and synergies

As we described above, significant efforts are made to improve farm management. While most work focusses on one aspect only, improvements simultaneously can have positive effects on different aspects. Reducing mineral nitrogen fertiliser applications, for example, may not only improve the efficiency of nitrogen use, but also reduce nitrous oxide (N_2O, a greenhouse gas) emissions. Improved management of soil organic matter may increase carbon sequestration, while at the same time improving nitrogen and water management by increasing nutrient availability and water holding capacity of the soil.

Whilst some measures are beneficial for more than one aspect, other measures, beneficial for one aspect, are counterproductive to other aspects. Some measures for improved nitrogen management (i.e. measures other than reducing mineral nitrogen fertiliser applications) may lead to increased greenhouse gas emissions. Slurry injection, for example, introduced in the 1980s as a means to reduce ammonia volatilisation, reduces ammonia-N emissions by some 90%, but requires extra energy for manure application. Increased soil mineral nitrogen availability, resulting from reduced ammonia volatilisation, may further increase denitrification and – hence – emission of nitrous oxide. In practice, however, farmers are advised to reduce application levels of mineral fertilisers when manure is injected. As the production (and transportation) of mineral fertilisers is an energy-consuming process, the net effect is not clear.

A trade-off between nitrogen and water management has been reported on 'De Marke', where it was found that irrigation in dry summers reduced nitrogen leaching, a finding that has been confirmed by model studies (Conijn and Henstra, 2003). Dry conditions may limit effective nitrogen management if mineralisation of soil organic matter after a period of prolonged drought exceeds uptake capacity of the crop, but it is not clear how often such a situation actually occurs. As a rule, large variations in water availability will limit effective nitrogen use. Such variations best are prevented, e.g. by improving irrigation or drainage.

Changes in water management should be applied with great care as they may affect carbon or nitrogen use efficiency. In the Netherlands, where ground water levels were lowered during the past decades in order to increase crop production, farmers are stimulated to help raising the groundwater level again as to favour the development of nature and biodiversity. This policy does however bring several risks. One risk is that phosphate may dissolve in the groundwater of the newly wetted soil layers. Further, increased water levels may enhance denitrification under conditions of intensive rainfall and, hence, nitrous-oxide emissions. As high groundwater levels increase the risk of nitrogen loss from the rooting zone, it may also lead to an increased demand for nitrogen fertilisers.

Summarising, changes in the agricultural production systems rarely affect one aspect of farming alone. Sometimes alterations can have positive effects on multiple aspects. Quite often improvements at one aspect may negatively affect other aspects. Proposed changes in nutrient (carbon, water) management should therefore be screened for side-effects, using an integrated approach that accounts for all relevant issues, processes and scale levels (Neeteson *et al*., 2002).

Discussion and conclusions

Over the last fifteen years, Agri-Environmental Indicators (AEIs) were developed and successfully applied in Dutch research, playing an important role in research projects like ‘De Marke’, ‘Cows and Opportunities’ and ‘Farming with a future’. AEIs helped to develop a common language which also was used in the design and setup of Dutch environmental legislation. Thanks to large investments in research and extension, nutrient (especially nitrogen) management improved considerably over the last years, a process where AEIs certainly played a role. AEIs were also applied succesfully in surrounding countries, as in least developed countries where nutrient budgets facilitated debates on soil fertility issues between policy makers, scientists and farmers (Scoones and Toulmin, 2002; Smaling *et al.*, 1999).

Application of AEIs is however limited, as they simplify spatially and temporally highly variable processes. The use of (for example) nitrogen budgets to compare operational management of different groups of farms would only be valid if such groups would be homogeneous with respect to activities and internal nutrient (carbon, water) flows at sub-farm level. Such comparisons are further sensitive to differences between farms with respect to the import of feed and fodder and export of manure (increased feed import and/or manure export leading to increase nitrogen use efficiency of farms with otherwise completely similar farming activities). As a rule, the scale at which AEIs are applied should reflect temporal and spatial variability within the farm system, as the scale determines to what extent peaks in losses can be compensated for by areas or time periods with lower losses. Application of too large a scale will easily lead to neglect of possible large internal variations and – hence – ocurring emissions. Factors causing variations that affect the relationship between AEIs and desired quality of air, water and soil are discussed by Schröder *et al*. (2003), Ten Berge (2002) and De Ruijter and Smit (2003).

Ideally, AEIs should be applied in an integrated evaluation of farming practices. Application in a specific aspect of farming, e.g. in nitrogen or water management only, can easily lead to the neglect of less favourable effects in other aspects. As processes determining availability of water, carbon and water are highly interacting, management of one aspect should also consider its effects on the other aspects. As a rule, nutrient management should aim at a balanced nutrient supply, avoiding peaks and extreme imbalances between the different nutrients. The use of aggregate AEIs, as used in in the evaluation of the condition of natural resources, may be helpful in this respect, as they can simultaneously evaluate nitrogen, water and carbon management.

Summarising, we conclude that AEIs are useful instruments in the communication among researchers and between researchers, farmers, consultants, and policy makers. Especially nitrogen budgets have proven to be efficient in interactive design, implementation and testing of more sustainable plant and animal production systems in the Netherlands. AEIs were calculated using farm data, soil, manure and plant samples as well as farm level experiments, literature data and complex biophysical models. As the indicators are simplifications of extremely variable and complex processes, they should, however, be used with great care, at all times remaining aware of the variability and detail lying behind the indicator values that are used.

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