FarmN: A Decision Support Tool for Managing Nitrogen Flow at the Farm Level

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Abstract

FarmN is a web-based, whole-farm model for nitrogen flow.

In this paper a prototype internet-based advisory tool is presented, the aim of which is to assist farmers and environmental regulators to agree on the production and losses of N to the environment under current and future conditions on a particular farm.

The system consists of an input part and a presentation part, and after users input, the presentation part can be consulted to view result in order to adjust input. To facilitate and minimize user input, the system contains functionalities to for example optimize crop rotations and to distribute manure.

Key words: Nitrogen flow, whole farm model, Internet, FarmN.

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1 Introduction

International legislation that focusses on the losses of N to the environment has a high impact on the management of farms in Denmark and on their ability to increase production. The N compounds controlled by legislation include nitrates (EU Nitrates Directive), ammonia (EU National Emissions Ceilings Directive) and nitrous oxide (UN Kyoto agreement on greenhouse gas emissions). The close relationship between farm N surplus and losses of N to the environment mean that N surplus is increasingly being used as an environmental indicator. An advantage of farm N surpluses is that they can be calculated quite accurately and reliably using readily available data at the individual farm, regional and national levels. This contrasts with field level N surpluses, where particularly on cattle farms, many of the internal flows cannot be easily measured.

In Denmark, use of such surpluses in environmental regulation is under review and the farming industry has shown interest in nutrient balances as a management tool. However, the integrative nature of N surpluses contrasts with national and international legislation, which relates to specific N compounds. Farmers and regulators need to estimate how farm N surpluses are partitioned between the different N loss routes, and on-farm accumulation of N. They also need tools to allow them to decide the most appropriate management to limit farm N surpluses. Losses of different N compounds are often linked, e.g. a new manure application technique to reduce ammonia volatilisation will increase amounts of N in the soil and could increase both nitrate leaching and nitrous oxide emission. It is therefore important to take a holistic approach to nutrient management.

The Danish government demands that applications for expansion of agricultural production facilities undergo a two-stage evaluation process. The first stage is intended to be a rapid screening, to determine whether the expansion is likely to lead to an unacceptable change in the impact of the farm on the environment. If this is unlikely, approval can be issued immediately. If there is a risk, the application must undergo a more detailed and rigorous environmental impact analysis. The intention with the tool described here is to assist in the rapid screening process.

There is a trade-off between the extent to which models can be tailored to the situation on an individual farm and the amount of data the user has to supply. More data input enables the results to be more precise but if too many data are required, many users will stop using the tool. Since this tool is intended for rapid screening, the emphasis here is on demanding relatively few data from users.

The focus in the tool presented here is on the interaction between plant and livestock production, since this largely determines the size of the N surplus and how it is partitioned between the different losses. The tool is based on a static model, meaning that the results should represent a medium-term average, rather than reflecting the specific conditions applying in a single year. The tool is deterministic, so the same input produces the same output. This whole-farm model for N flow is referred to as FarmN tool. The tool is implemented on the Internet and can be accessed via: http://www.Farm-n.dk/FarmNTool.

The focus in this paper is to describe the FarmN tool in detail. Section 2 describes the information needed to run the model and the results presented. In section 3, the underlying flows and models used to calculate the results are described. In section 4, we describe the architecture of the system and in section 5 discuss the strengths and limitations of the approach adopted here.

2 System overview

This system consists of a collection of tab pages, each of which dealing with different parts of either user input or calculated output. Since information about the users farm, fields, livestock and so on has to be stored in the system, a user login system has been implemented. This means that users can return to the same data next time they login. After login the browser looks as shown in figure 1. Several different scenarios can be stored and adjusted to see the results of different management decisions. Data that are identical for the scenarios such as farm data and location only has to be entered once.

Another feature is that all text strings in the system are stored in a language table in the database. Thus users, before login, can choose between different languages.

Now we will go through the tab pages and identify the purpose, the required input and the output presented by each page. The idea is that the tab pages can be filled in or selected in any order, but since most calculations presupposes certain user inputs, the best procedure is to go through the tab pages from left to right.

2.1 Farm tab page

After login the Farm tab page is the first to be presented (figure 1). Here information about the farm is requested:

- Name, address etc.
- Default soil type (can be overruled later)
- Default irrigation possibilities (can be overruled later)
- Default yield level (can be overruled later)
- Type of farming (whether it is mainly plant production or animal production)

The relevant scenario is defined or selected, and for each scenario, information on bought or sold manure can be input. Users can create, edit and delete scenarios. All input in the other pages is for the scenario specified here.

On all tab pages changes must be saved before leaving the tab page or using any ‘new’ button.’

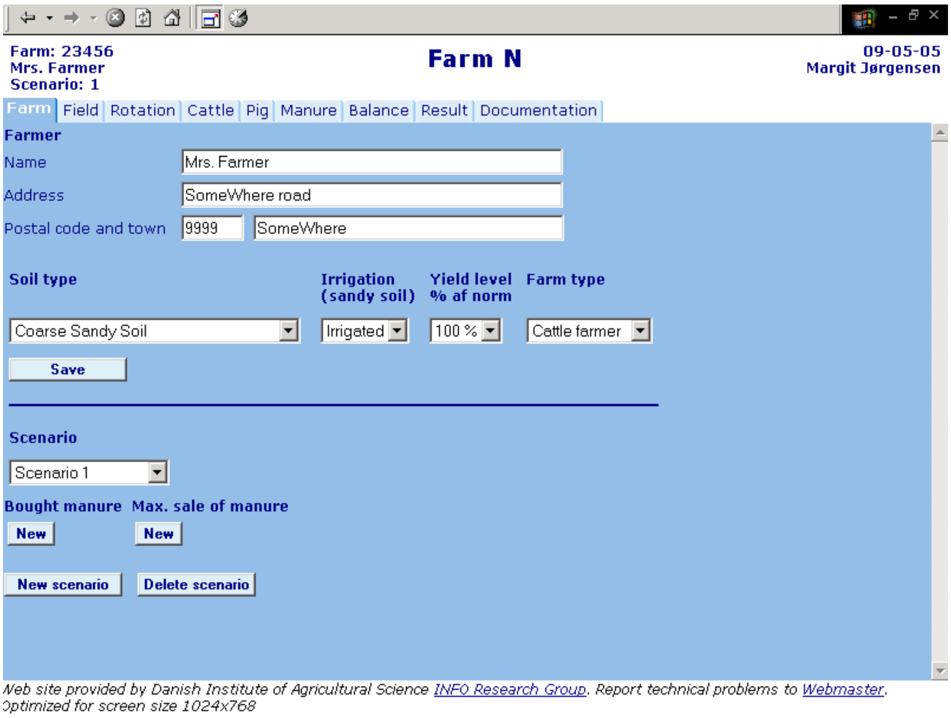

Figure 1: The Farm tab page.

2.2 Field tab page

In this page, the user supplies information on the plant production. The user has to specify which crops are grown in the same rotation, in addition to the area occupied by each crop. Several crop rotations can be created for each scenario. When a rotation is created, default values for soil type, irrigation and yield level are presented (as selected on the Farm tab page) but may be changed individually for each rotation. The default crop yields in the system are currently those presented in Plantedirektoratet, 2003.

2.3 Rotation tab page

Based on the user-defined information describing cropping, area, soil type, irrigation and yield level, together with default information on crop/previous crop yield (Plantedirektoratet, 2003), a rotation model (Detlefsen 2004) is used to calculate the optimum sequence of cropping in each of the rotations.

For each crop, the user can enter information on:

- Whether or not to spread manure on a particular crop on a particular field.
- The maximum proportion of the yield that is used for grazing (if relevant).
- The maximum proportion of the yield that is sold.
- How to treat the straw (chopped and ploughed in, for sale or for own use).

2.4 Cattle tab page

The purpose of this page is to give information on cattle production. Information about livestock includes:

- Number and types (currently a choice between Holstein and Jersey, in addition to dairy, heifers and young bulls).
- Production level (either milk per year or weight gain per day).
- Efficiency level.

- Maximum amount of feed units supplied by grazing.
- Livestock housing type.

Based on user input and standard values (Poulsen et al., 2001), calculations are made concerning feeding requirements, production of milk, meat and manure.

2.5 Pig tab page

The purpose of this page is for users to provide information on pig production. Input is divided into two parts, one for sows and one for piglets and finishing pigs. For sows, the number of annual sows is input (annual sow = sow places × proportion of year occupied). For piglets, the inputs are the average number of (live) piglets per sow, the weight of these piglets at weaning, the amount of feed per sow and its protein content, and the housing types for both pregnant and lactating sows. For piglets and finishing pigs, the inputs are the number of animals produced, the start weight and end weight, the amount of feed and its protein content and finally the housing type. Based on these inputs the system calculates the total feeding requirements and the production of meat, animals and manure, based on standard values in Poulsen et al., 2001.

This is the last page where the user applies input. The remaining tab pages calculate results of the input and present them in various ways.

2.6 Manure tab page

Based on the livestock input this page presents an overview over manure production and ammonia losses. It also shows to which fields manure is applied and the manure application method chosen.

2.7 Balance tab page

On this page, the internal flow of nitrogen on farm is shown, plus some key figures regarding the production. On the top of the page, there are calculations regarding manure and at the bottom there are results regarding feeding of the animals including the fodder produced on farm. Key figures presented regarding manure are, for example, mean utilization degree and total losses in housing and storages. Key figures presented for the feeding are efficiencies related to cattle feeding, including how much feeding is bought.

The idea is that the user should agree with the results shown, otherwise the appropriate inputs should be adjusted on the previous tab pages.

2.8 Result tab page

On this page, the external flow of N is shown. The inputs of N to the farm are from fertilizer, manure, fodder, livestock, seeds, atmospheric deposition and fixation. The N outputs from the farm area as crop products, livestock, meat, milk, manure and fodder. The N surplus of the farm is the difference between the two figures. Finally, the N surplus is partitioned into ammonia volatilisation, dinitrogen and nitrous oxide emissions due to denitrification, nitrate leaching and changes in the N stored in the soil. The gaseous emissions are presented separately for the animal housing, manure storage and fields.

2.9 Documentation

This page contains a description of the formulas and assumptions used in the system.

3 Principles of the production system

In this section, the assumptions concerning farm management that underlie the flows of N will be described. These assumptions relate to the interaction between the crop production and the livestock husbandry. These assumptions are necessary in order to translate farm management decisions (e.g. to grow other crops or to increase livestock production) into N flows.

First, the flow of manure on the farm from the animals to the fields is described, using the functions of Poulsen et al., 2001. The amount of N excreted by the animals is calculated, based on the amount and type of feed consumed and the production of milk/meat. If the cattle are grazed, the proportion of the annual manure production that is deposited directly onto the field is assumed to correspond to the fraction of the total energy intake that is consumed by grazing. A proportion of the N in this manure is calculated to be lost via ammonia volatilisation. The remaining manure is then partitioned into slurry and deep litter according to the stable type in which the animals are kept. N in straw is added into the manure-type that is relevant for the stable type. The housing-specific loss of N as ammonia is then calculated and subtracted from the N excreted in housing, enabling the calculation of the N in each manure type ex housing. The storage losses are then calculated. These consist of the volatilisation of ammonia and the emission of dinitrogen and nitrous oxide via denitrification. Deducting the storage losses gives the N ex storage for each manure type. The manure types used in the model are manure deposited on grass from grazing, slurry and deep litter from cattle and slurry and deep litter from pigs. If manure of a given type is bought, it is added to the manure produced on farm. It is assumed that the housing and storage losses occur on the farm producing the manure and only field losses occur on the recipient farm. Likewise, if manure is sold, it is assumed that this occurs after storage, so housing and storage losses are deducted and included in the farm balance.

In Denmark, the N use on farms is regulated according to a system that takes into account the mineral N that must be applied to obtain the economic optimum yield from any particular crop and the assumed fertiliser equivalent of different manure types (Plantedirektoratet, 2003). Under the Danish rules, the farmers are permitted to fertilise to 90% of the economic optimum and it is assumed that the farmers fertilise up to this limit. The model uses the Danish rules to control how much fertilizer the farmer is allowed to buy, based on the crops grown and the manure produced. To do so, the mineral N permitted on each of the fields in the crop rotation is first determined. The fertilizer equivalent of the manure is then calculated, using a standard value that varies with manure type. If the mineral N from the manure is insufficient to fill the mineral N quota, the farmer is allowed to buy the difference as fertilizer N.

Manure that remains on the farm after any sale has to be applied to the fields that are allowed to receive manure (input from the crop rotation tab page). Using utilization rates that are specific for each crop, manure and application technique, the manure and mineral fertilizer are distributed in such a way that the utilization of the manure is maximized. After the manure and mineral fertilizer has been distributed to the fields the spreading loss is calculated, using standard values for the volatilisation of ammonia from the mineral fertiliser N applied.

On farms with cattle, feeding and plant production are closely linked and this is an important part of the FarmN tool. Based on the data input regarding crops and areas we use the model described in (Detlefsen, 2004) to calculate the crop rotation. The crop rotation has to be reasonable in the sense that it is not an applicable production plan but more a reliable average crop rotation over some years. The result from the model is the history of each crop. Based on these crop rotations and inputs regarding the utilisation of grazing fields, the model uses Danish standard values to calculate the yield and N content of grazed and cut roughage and of cereals. Based on the user inputs of annual milk yield and animal growth, the energy and N demand of the herd is calculated. The energy to be supplied by roughage is calculated using Danish standard values. The N supplied by this roughage is also calculated, based on standard values for the concentration of N per unit energy. If the roughage production on the farm is insufficient, roughage is bought that has the same concentration of N as in the roughage produced and if there is a surplus of roughage, it is sold. The remaining energy and N demand of the herd has to be supplied by supplementary feeding. The model first seeks to satisfy the demand for supplementary feed with cereal produced on the farm. If this is insufficient, then supplementary feed is bought that has an N concentration necessary to fulfil the herd requirement. It is possible that the required N concentration is lower than the lowest N concentration of the supplementary feed available (wheat). If this is the case, then the system will satisfy the herd energy requirement and the N content in the feeds will exceed the herd N requirement. Cereal crop production that is not used as supplementary feed is sold.

All pig feed is assumed to be bought, so there is no interaction between the feeding of pigs and the plant production.

The model calculates straw production and use on the farm. On the crop rotation tab page, the user has to select whether the straw that is produced is used for bedding, is sold or is chopped and returned to the soil. Based on the number of animals and the animal housing type, the need for straw in livestock husbandry is calculated. If there is insufficient straw produced, the deficit will be bought and if there is a surplus, it will be sold.

Fixation of N from the atmosphere is set constant per crop. In grain legumes the fixation is calculated from average grain yield and the coefficients of Høgh-Jensen et al (2003). In mixed crops (grasses/cereals/legumes) the fixation is set to average estimated values on conventional study farms, Halberg et al (1995). Denitrification in the soil is calculated by means of the SimDen model (Vinther, 2004), and changes in the N stored in soil organic matter are calculated according to Gyldenkærne et al., 2005. Nitrate leaching is determined as the difference between the farm N surplus and the sum of the losses from animal housing, storage, manure and fertilizer applications and denitrification and the change in the N stored in the soil.

4 System design

The system follows a three-layer approach: database, model and presentation.

4.1 Database

The system depends heavily on data stored in the database (MS SQL Server). Data is extracted by calling Stored Procedures or User Defined Functions with parameters in TSQL on the database server. Many calculations are performed in these Procedures or Functions.

4.2 Model

The models use VBScript and TSQL in MS SQL Server. Examples of models are

- Rotation model for creating the crop rotations (Detlefsen, 2004)
- Soil change model for calculating nitrogen accumulated in the soil (Gyldenkærne, 2005).

4.3 Presentation

Active Server Pages with VBScript and Jscript is used for the presentation layer. A collection of general functions and subroutines facilitates the overview and minimizes the number of code lines.

5. Discussion

In this paper, we have described a prototype of an advisory tool that aims to assist farmers and environmental regulators to rapidly agree on the production and losses of N to the environment under current and future conditions on a particular farm. To construct a tool that is suitable for making a rapid assessment (screening), the inputs demanded from the user have been kept to a minimum. This has meant that many assumptions have been made, the most important of which have been described above. The extensive use of simplifying assumptions limits the complexity that can be introduced in the underlying model. This means that the best one can hope is that the results are valid for an average farm that has the particular combination of livestock, manure management system, cropping and soil type. In addition, whilst the farm N surplus is likely to be quite well predicted, the partitioning of that surplus between the various sources of loss is likely to be much less certain. One of the strengths of the system is its ability to simulate the cascade of N through the manure handling system and finally to field application or export from the farm. However, this also means that errors in predictions will tend to be propagated forwards, such that the absolute error in the prediction of losses from the field (especially via nitrate leaching) will tend to be higher than those from animal housing or manure storage.

The tool described here is build upon the Danish regulations and the underlying assumption is that a nutrient quota is used to regulate management. In the current version of the tool, this quota is for mineral N but we plan discussions with the regulatory authorities in Denmark to include P. We have also begun discussions with other countries that also use a quota system. Since different countries use different units to measure crop and livestock production and the production in different countries has to fulfil different rules, we intent to develop a system where the user can choose the country/rules/units.

The advantages of basing the tool on the Internet, rather than as stand-alone software, are ease of updating and possibilities to link to existing databases for soil or farm data. The possibilities to link to existing databases will reduce the amount of data input needed.

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