FIONA 1.0

Technical description

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Inhoud

Samenvatting

FIONA (Farm-scale Integrated Optimisation model of Nature and Agriculture) is een optimaliseringsmodel dat is toegespitst op de inpasbaarheid van verschillende vormen van natuurbeheer op graasdierhouderijen. Het model wordt onder andere toegepast in beleidsanalyses voor het Milieu- en Natuurplanbureau en in pilotprojecten voor agrarisch natuurbeheer zoals Boeren Voor Natuur.

FIONA maximaliseert het bedrijfssaldo binnen een aantal restricties die met elkaar de structuur weergeven van het bedrijf waarop het model wordt toegepast. Het model bestaat uit vijf onderdelen: een veemodule, voer- en landgebruiksmodule, een arbeidsmodule, een nutriëntenmodule en een doelmodule. Op de doelmodule na, die het bedrijfssaldo berekent, beschrijft iedere module een bedrijfsonderdeel.

De veemodule berekent hoeveel vee het bedrijf kan houden, hoeveel inkomen het vee oplevert en welke voedereisen door de veestapel worden gesteld, welke kosten voor het vee worden gemaakt en hoeveel arbeid voor het vee nodig is. De voedereisen gaan vervolgens naar de voer- en landgebruiksmodule en de mestproductie gaat naar de nutriëntenmodule. Daarnaast wordt de benodigde arbeid doorgegeven aan de arbeidsmodule, en worden de kosten en baten van het vee doorgegeven aan de doelmodule.

De voer- en landgebruiksmodule berekent hoe aan de voedereisen van het vee kan worden voldaan, hoeveel moet worden aangekocht en geproduceerd, en hoeveel land en arbeid daarvoor nodig is. Deze module is voor het natuurbeheer van bijzonder belang, omdat natuurbeheer in FIONA wordt gehanteerd als een vorm van landgebruik. Van de voer- en landgebruiksmodule gaat de nutriëntenbehoefte van het gewas naar de nutriëntenmodule, de benodigde arbeid naar de arbeidsmodule, en de directe kosten en baten van het landgebruik naar de doelmodule.

De nutriëntenmodule berekent aan de hand van de hoeveelheid mest die wordt geproduceerd door het aanwezige vee en de hoeveelheid nutriënten die nodig zijn voor het gewas hoeveel mest moet worden afgevoerd en/of hoeveel kunstmest moet worden aangekocht. De hoeveelheid arbeid die nodig is voor werkzaamheden in deze module wordt doorgegeven naar de arbeidsmodule, en de kosten die voor mest worden gemaakt worden doorgegeven naar de doelmodule.

De arbeidsmodule berekent hoeveel arbeid nodig is voor de verschillende werkzaamheden op het bedrijf, hoeveel arbeid beschikbaar is en daarmee hoeveel arbeid moet worden ingehuurd. De kosten van het inhuren van arbeid worden weer doorgegeven naar de doelmodule.

Tot de invoergegevens van FIONA behoren biofysische, bedrijfsspecifieke en financiële gegevens. De biofysische invoergegevens hebben o.a. betrekking op de voedereisen van het vee en de gewasproductie van verschillende voedergewassen. Bedrijfsspecifieke gegevens hebben o.a. betrekking op de omvang van de stal, de aanwezige percelen en hun oppervlakte en de gemiddelde melkproductie per melkkoe. Tot de financiële invoergegevens in FIONA behoren allerhande prijzen van productiefactoren zoals arbeid, kunstmest, ruwvoer en krachtvoer, maar natuurlijk ook van verkoopproducten zoals melk en vlees, en subsidies voor agrarisch natuurbeheer.

Summary

FIONA (Farm-scale Integrated Optimization model of Nature and Agriculture) is an optimization model focused on different forms of nature management on cattle farms. The model is applied in policy analyses for the Nature Policy Assessment Office and in pilot projects for agricultural nature management such as Farming for Nature.

FIONA maximizes the farm's financial balance within a set of restrictions that describe the structure of the farm under consideration. The model consists of five parts: a cattle module, a fodder accounting and land use module, a labour module, a soil nutrient module and an objective module. Apart from the objective module, which calculates the financial balance, all modules describe a different part of the farm.

The cattle module calculates the number of cattle that the farm can keep, its direct benefits, its fodder demands, its direct costs and its labour demand. The fodder demands go into the fodder accounting and land use module, whereas the amount of manure produced is used in the soil nutrient module. The amount of labour needed goes into the labour module and the direct costs and benefits go into the objective module.

The fodder accounting and land use module calculates how the farm can meet the cattle's fodder demands by production and purchase, how much fodder can be sold and how much land is needed for this. This module is particularly important for nature management, because FIONA treats all agri-environment contracts as a form of land use. Soil nutrients needed for fodder production are feeded into the soil nutrient module, labour demands go into the labour module and the direct costs and benefits of land use go into the objective module.

Given the amount of manure produced, and the amount of nutrients needed for fodder production, the soil nutrient module calculates how much fertilizer needs to be purchased and how much manure must be removed from the farm. Labour demands with regard to manure go into the labour module, and the direct costs of nutrients use go into the objective module. The labour module calculates the amount of labour needed for the different activities that take place on the farm, how much labour is available and how much needs to be rented. Costs of labour go into the objective module.

The input data of FIONA include biophysical, farm specific and financial data. Biophysical data include the fodder demands of different types of cattle, and the production of different types of fodder. Farm specific data include the size and type of the stable, the available plots and their size, and average milk production per cow. Financial input data include prices of different production factors such as labour, fertilizer, fodder and concentrates, but also sales products such as milk and meat, and subsidies for nature management.

1   Introduction

1.1   Introduction

The farm management model FIONA (Farm-scale Integrated Optimisation model of Nature and Agriculture) has been developed at the Agricultural Economics Research Institute, and applied in several projects with regard to agricultural nature management. So far, however, the model has not been properly documented.

The purpose of this report is to provide a description of the model that is accessible to potential users, developers and reviewers. The report is intended as a first acquaintance with the model, rather than an exact technical description. For the exact technical structure of the model we would rather refer to the original source code. This report is also meant as a guide to the FIONA source code.

The report is organised as follows. In the remainder of this chapter, we explain the background, history and objectives of FIONA, as well as what the model is *not* developed for. Chapter 2 introduces the general structure of the model, the input it requires and the output it gives. Chapters 3-6 explain the different model parts or modules. Chapter 7 discusses the state of affairs as well as possible or preferred future developments of the model.

1.2   History and application of FIONA

FIONA is based on the linear farm management model developed by Berentsen (1999). Whereas Berentsen's model is used for general questions regarding sustainable dairy farming, however, FIONA focuses on the implementation of nature management in cattle farms. As such, FIONA is applied in several research projects such as Farming For Nature (Stortelder et al. 2001) and analyses of Dutch agri-environment policies for the Netherlands Environmental Assessment Agency (see e.g. Schrijver et al. 2005).

Farming for Nature is a Dutch pilot project with an integrated whole region approach with regard to implementation of agri-environment schemes. The aim of the project is to develop a new organic high level stewardship scheme for farms within the inner circle of an important nature conservation area and a new countryside stewardship scheme for farms surrounding the inner circle. Farms outside this second perimeter only have to abide to good farming practices. The highest level stewardship farms adapt to a zero input system.

Analyses with FIONA for the Netherlands Environmental Assessment Agency focus on the potential involvement of farmers in nature policies through agri-environment schemes. The main Dutch agri-environment scheme, the Subsidieregeling Agrarisch Natuurbeheer or SAN (DR 2005), was implemented in FIONA by Schrijver et al. (2005). The analyses are typically done by running the model for a representative set of farms in order to assess the area of SAN-contracts that can potentially be realised. Efforts to implement another scheme, the Subsidieregeling Natuurbeheer or SN (DR 2006b), are currently in progress.

1.3 Model purpose and demarcation

The main topic to be investigated by FIONA is the implementation of nature management activities on cattle farms. The model is used by calculating the short-term farming strategy that maximizes the farm's financial balance. Therefore, FIONA necessarily assumes that the farming strategy calculated by the model is repeated annually. This assumption restricts the endogenous variables to decisions with a time horizon of one year or less. Examples of such decisions are the amount of fodder purchased and the area of arable crops within the available land area of the farm. Decisions with a longer time horizon, such as the size of the stable, are exogenous inputs to the model.

So far, arable farming is only included as far as it is relevant for cattle farms. Currently, FIONA is even restricted to dairy farming, although efforts to include other cattle types such as suckler cows and sheep are in progress. For the time being, the model remains restricted to cattle farming because analyses of arable farms may require a model that is very different from FIONA. However, the technical consequences of including arable farming in FIONA are not sufficiently clear to rule this option out completely.

A similar remark as with regard to arable farming can also be made with regard to types of nature conservation that are not particularly relevant for agriculture. Management of nature types such as salt marshes and forests have so far been excluded, although we cannot fully rule out that they may be introduced in the model in the future.

2 General model set-up

2.1 Model type and software

FIONA is a farm-level linear programming model that describes the structure of a dairy farm in a high level of detail. Its general structure can thus be summarized by the standard structure of a linear programming problem:

$$\text{maximize } \{y = \boldsymbol{c'x}\} \text{ such that}$$
$$\boldsymbol{Ax} = \boldsymbol{b},$$

where y denotes the objective variable that is to be maximized, $\boldsymbol{x}$ is a vector with choice variables, $\boldsymbol{c}$ is a vector with benefits or pay-offs from $\boldsymbol{x}$, $\boldsymbol{A}$ is a matrix of restrictions to the problem and $\boldsymbol{b}$ is a vector with values to the restrictions.

In FIONA the objective variable is the farm's financial balance, whereas the vector x includes all variables a farmer must decide upon in order to run his farm. Hence, x includes which fodder crops are produced in what quantity, how much is purchased or sold on the market, how much livestock is present on the farm, etc. The values of these variables are subject to several technical and biological restrictions represented in the matrix A. Examples of such restrictions are that the surface area of grassland and arable land of the farm cannot exceed the overall surface area of the farm, or that enough fodder must either be produced or purchased to feed cattle. Hence, the restrictions included in A describe the geographical, technical and biological structure of the farm.

The current version of FIONA is written in GAMS. As the model is a linear programming model, it is best run with LP solvers such as CPLEX, although MINOS also performs relatively well. In the future, however, integer variables may also be introduced to the model[1]. In that case, the use of a MIP (Mixed Integer Programming) solver becomes necessary. The only MIP solvers currently available at LEI are BDMLP and CPLEX. However, we discourage the use of BDMLP for FIONA (or any other large MIP model) as this solver is generally very inefficient.

2.2 General organisation

The modular structure of FIONA is given in Figure 1. The input of the model consists of general technical and financial data as well as data specific for the situation modelled. These input data are translated into model parameter values in a series of precalculations. The core of the model is the optimisation model, which includes the objective function and the restrictions to the instrument variables. After the model is run the results are summarized by a report module.

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[1] For instance, the current version of FIONA allows for patches of land use that are too small to be profitable in practice. This problem may be solved by demanding that the area of that particular land use is either zero or larger than some positive figure. Such a change would, however, introduce an integer variable that determines whether the land use type is present at all or not. A more straightforward, but less urgent, example is the number of cattle on the farm. This number is continuous in the current version of FIONA.

The optimization model is divided in five different modules in order to separate different functionalities and to make it possible to substitute part of the model by an update or a special case. The five modules are:

- The cattle module, which includes restrictions with regard to the size and composition of the livestock herd and the herd's fodder demand;
- The fodder and land use module, which includes restrictions with regard to supply, production, purchase and sales of production, and other kinds of land use such as agri-environment schemes;
- The nutrient module, which includes restrictions with regard to the input of and demand for nutrients on the farm;
- The labour module, which includes restrictions with regard to the input of labour;
- The objective module, which includes all objective variables the user may choose to apply in the analysis.
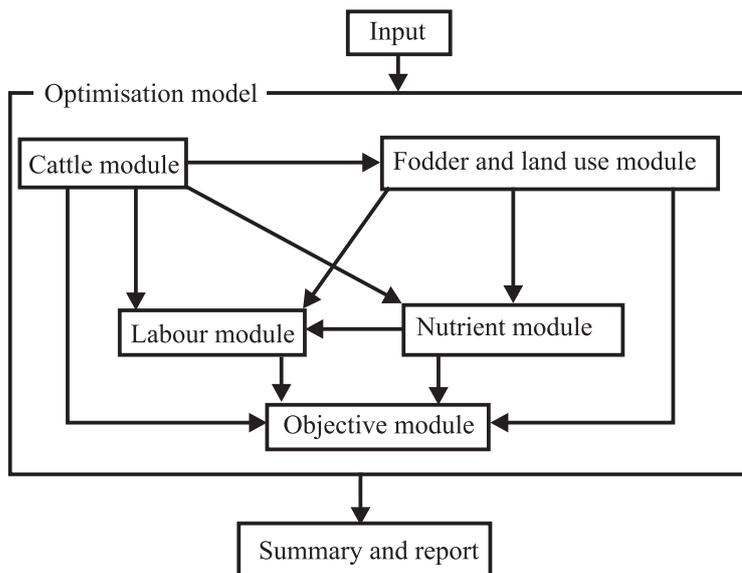
Figure 1: General structure of FIONA

In the remainder of this chapter we will explain the general input, objective variables and output of FIONA in more detail. The four main modules of FIONA (cattle, fodder and land use, nutrients, and labour) are explained in further detail in Chapters 3-6.

2.3   Input

LEI models such as DRAM (Helming 2005) and AG-MEMOD (van Leeuwen and Tabeau 2005) are econometric models that include generalised relations rather than explicit technical relations. These models are therefore parameterised by fitting them to real world observations. FIONA, on the other hand, is a technical model that explicitly includes the mechanisms relevant to the model. Therefore, it uses a large amount of biological, geographical and financial input. Four main groups of input can be distinguished:

- Data specific for a particular module;
- Data specific for the farm or farms under consideration;
- Financial data that may need to be updated regularly;
- General data that cannot be ascribed to a particular case or module.

We will discuss the data specific for a particular module in the chapter for that module. The other types of input data are described in the following paragraphs.

2.3.1 Farm specific input data

The input data specific for the case or area under consideration include:
- The plots and farms in the study area;
- The user structure, i.e. which plots are used by each farm;
- The biophysical and geographical properties of each plot;
- The technical properties of each farm.

FIONA is written such that it can in principle include several farms at a time, although the model does not yet include any relations between farms[2]. Therefore, the user needs to specify which plots are used by which farm. This ownership structure (or rather usership structure) also determines the distance between the plot and the farm and whether the plot should be considered a field plot or a home plot. Home plots can generally be accessed by the farm that uses them without having to cross roads and such. Therefore, the farmer can use these plots to graze dairy cattle, which has to be taken into the milking parlour several times a day. Field plots lie further afield, which makes them impractical for grazing dairy cattle. Furthermore, the distance between plot and farm also determines the costs of using the plot and the amount of labour needed to work on it. Besides these geographical properties, biophysical properties such as soil type are important as they determine fodder production.

The technical properties of the farm describe the size, mechanisation level and inner workings of the farm. They include the milk quota owned by the farm, the capacity of the stable for several types of cattle, and the amount of on-farm labour available. The mechanisation level is specified by the type of milking parlour, type of stable, and the presence of machines such as a concentrates machine.

The user also specifies the grazing system of the farm, which indicates whether and when cattle grazes or is kept indoors. So far, the model includes three grazing systems:
- Day and night grazing: in the grazing season cattle is kept on pastures day and night, and in the stable season cattle is kept indoors all day;
- Day grazing only: in the grazing season cattle grazes on the pastures at day and is kept indoors at night, whereas in the stable season cattle is kept indoors all day.
- Stable feeding: cattle is kept indoors all day, all year.

The calving pattern is also important as it indicates how many calves are born on average throughout the year. Most farms have a spread calving pattern, where the number of calves born per cow is roughly constant over the year. Some farms, however, aim to have more calves born in autumn than in other times of the year, in order to produce more milk in autumn and winter, when the average milk price is higher.

In analyses of a real single farm the farm-specific input will probably come from the farm itself. FIONA has, however, also been applied in many studies where large groups of farms are analysed. In these cases not all data will be available, so that these parameters need to be filled in by an educated guess.

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[2] The main reason to include several farms in one optimisation is because they may influence each other by trade or by use of common lands. If there are no such interdependencies, it is more efficient to run the model for each farm separately.

2.3.2 Financial data

All financial input data are put together in one module in order to be able to update these data all at once. Table 1 shows the main categories of financial input data and their sources for the current dataset. By far the most important source is the periodical *Kwantitatieve Informatie Veehouderij* (ASG 2003), but additional sources, for instance on subsidies for agri-environment schemes, are also used.

Table 1: Financial input data for FIONA and their sources

Category	Source
General	
Costs of mechanisation	ASG 2003
Interest rate	DNB 2004
Costs of owning or renting plots	DLG 2005
Cattle	
Market price of milk, meat and livestock	ASG 2003
Costs of maintenance and health care	ASG 2003
Price of hiring milk quota	ASG 2003
Fodder and land use	
Market price of fodder	ASG 2003
Subsidies for particular forms of land use	ASG 2003; LASER 2004
Fodder stock costs	ASG 2003
Transport costs of land use types	ASG 2003
Costs of harvesting, maintenance, renewal, etc.	ASG 2003
Nutrients	
Price of nitrogen fertiliser	ASG 2003
Costs of stocking and removing manure	ASG 2003
Labour	
Wages for low-skilled labour	ASG 2003

2.3.3 General data

General data include
- a number of sets to indicate time;
- the fodder types, cattle types, land use types and soil types available;
- a number of very general parameters such as the number of days in each month.

The time dimension in FIONA
Three general sets are used to indicate time in FIONA. The easiest interpretable set would be the calendar month, which is needed because many input data are specified per month. In the optimisation model, however, the year is not divided in months, but in feeding periods. The feeding period is the basic indicator of when a particular activity takes place, or is needed. The reason that FIONA uses feeding periods instead of calendar months is that it provides

more freedom with regard to the level of detail needed in the time dimension: in principle, the year can be divided in as few as two or as many as 365 feeding periods. Currently, most feeding periods are about 15-16 days long, except for those in the last months of the year (where one feeding period covers October, November and December), and those in June (where each feeding period is about a week long to allow for four different extended mowing dates).

The third indicator of time, the harvesting period, should be treated as an indicator of quality rather than time. The reason to include a different time indicator for harvesting than for feeding is that an amount of fodder harvested in May can be given to cattle all year. Furthermore, grass mown for silage in May will have a different quality than grass mown in, say, July or August. The harvesting period can therefore be compared to the year on a bottle of red wine: it gives information on when it is made and on its quality, but not on when it is consumed.

Besides calendar months, feeding periods and harvesting periods, some minor sets are used to indicate specific periods of the year. For instance, sub groups of feeding periods and harvesting periods are made to distinguish the growing or grazing season, when land is used to graze cattle and to harvest fodder, from the stable season when no fodder is harvested and cattle is kept indoors. Another set distinguishes periods of the year that determine the price of milk.

Fodder types, land cover types and land use types

Fodder types can be roughly categorised in grass, arable crops and concentrates. Each of these three groups includes several fodder types (for instance, grass includes freshly mown grass, grazed grass, grass silage and hay), but regarding their relation to land use there are important differences between these groups.

Besides fodder types, the model also distinguishes land *use* types and land *cover* types. Land cover types refer to the general function of land and include such types as grassland and arable land. A land cover type is therefore constant over the year. Land *use* types refer to what happens to the land. For instance, it can be mown or grazed, and several types of crops can be grown on it. Because the same plot of grassland can be mown or grazed several times in one year, land use types include a time dimension because most of them change over the year. Yields are also attached to land use types: after all, it is the mowing, grazing or harvesting that yields the fodder.

Looking at the three main fodder types, the land use types that yield them and the land cover types where each land use type can be allocated, we see the following characteristics distinguish each group. Grass can be mown or grazed in each feeding period in the grazing season, which implies that the model includes such land uses as mowing grass or grazing grass. Each of these land use types, however, will yield a different type of grass. For instance, mowing grass for silage is assumed to yield grass silage[3] which has a lower overall fodder quality than freshly grazed grass, and mowing grass under an extended mowing programme will yield hay with a very low quality. The land use types that yield grass can only be allocated to grassland. Although the model generally allows for purchases and sales of grass, it is not very likely, so it might as well be switched off.

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[3] Taking into account, of course, storage costs, losses of dry matter and quality due to ensiling, etcetera.

Arable crops include such fodder types as maize and fodder beet. These crops differ from grass in that they can be harvested only once a year. Nevertheless, one harvest of an arable crop is assumed to keep the land occupied for the entire growing season. Arable crops can also be purchased from or sold on the local market. The model includes a different land use type for each arable fodder type (say, maize comes from 'harvesting maize'). Also, each arable land use type has its own land cover type ('harvesting maize' can only be done on 'maize land').

The last category, concentrates, cannot be produced, so that the farmer has to buy them on the market. Because such variables as fodder supply are defined not only per fodder type, but also per land use type, we need to specify a land use type that 'yields' concentrates. Therefore, the model includes a land use type 'buying fodder' that yields fodder types that cannot be produced on the farm, and whose area is set to zero.

Soil types
Soil types included in the model are the ones most prominent in The Netherlands, namely sand, clay and peat.

General parameters
The general input parameters mostly include obvious data such as the number of days in each month, the number of weeks in a year, the number of grams in a kilogram, etc. They also include the length of each feeding period. The length of harvesting periods is set to their corresponding feeding periods.

2.4 Objective variable

For a single farm, the model is run to maximize its net income. Because the model can in principle include multiple farms, however, some rule is needed to translate the net incomes of all farms to a single measure. The current version of FIONA can maximize either one of the following two objective variables:
- The sum of all farm incomes;
- The farm income of the 'poorest' farm, i.e. the farm with the lowest farm income.

2.5 Output

The model output consists of the values of all instrument variables and the objective variable. Because of the large amount of dimensions and variables, the output is summarized in a number of summary parameters that denote the following:
- The number of livestock in each livestock category;
- The area of each land cover type;
- The area of each land use type in each feeding period;
- The amount of fodder purchased or sold;
- The amount of fodder produced;
- The amount of labour hired or letted;
- The amount of milk quota hired or letted;
- The amount of fertilizer purchased;
- The amount of manure removed.

3 Cattle module

3.1 Introduction

The cattle module includes all restrictions with regard to the composition and the size of the livestock herd, production and sales of milk and cattle, as well as the feeding requirements of livestock.

3.2 Feeding requirements

Demand for fodder is expressed in four fodder requirements:
- Energy, expressed in VEM[4];
- Intestine digestible protein, expressed in kg DVE[5];
- Rumen degradable protein balance, expressed in kg OEB[6];
- Fibre content, expressed by a coefficient.

The requirements per cow with regard to energy and intestine digestible protein are exogenous to the optimisation model. Before the optimisation model is run, FIONA calculates these values from farm-specific data such as average milk production, grazing system and calving pattern, based on insights published in Hijink and Meijer (1987) and CVB (2002). These requirements vary throughout the year due to variation in grazing, milk production, pregnancy and growth. Therefore, the grazing system is important for these requirements as it determines how much energy and protein is needed for grazing, and the calving pattern is important as it determines how much energy and protein is needed for pregnancy, growth and milk production.

The rumen degradable protein balance of the feed ration should simply be kept non-negative throughout the year (Tamminga et al. 1994). Fodder types such as maize and fodder beet generally have a negative OEB value, whereas grass and concentrates have a positive OEB value. This requirement therefore restricts the amount of most arable crops that can be given to cattle.

The fibre content indicates the average amount of fibre in the feed ration, expressed by a dimensionless indicator. Under the current system of calculating the desired fibre content the average value of the indicator should be about 1.0 or higher (Boxem 1999; CVB 2002).

3.3 Fodder intake capacity

The amount of fodder that cattle can stomach depends on two things. On one hand, fodder intake is restricted by the intake capacity of the cattle, which may be loosely interpreted as

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[4] VEM (Voeder Eenheid Melk) is the Dutch counterpart of Joules Net Energy for Lactation (J NEL). 1 VEM = 6.9 kJ NEL.

[5] DVE (Darm Verteerbaar Eiwit) is a Dutch measure for Intestine Digestible Protein (Tamminga et al. 1994)

[6] OEB (Onbestendig Eiwit Balans) is a Dutch measure for the rumen degradable protein balance (Tamminga et al. 1994)

the size of their stomachs. On the other hand, cattle can stomach different amounts of different fodder types. The fodder intake capacity is exogenous to the optimisation model. The values for dairy cattle are calculated according to Zom et al. (2002), whereas they are taken directly from CVB (2002) for young cattle.

3.4 Livestock herd composition and size

The size of the livestock herd will mostly be bounded by the capacity of the stable, but if there is a restriction on the renting of milk quota the available milk quota can also restrict the number of livestock. Both data come from the individual farm itself.

The number of calves and yearlings per dairy cow is also exogenous to the optimisation model. This is due to the assumption that the farm sells a fixed proportion of dairy cows each year, which is expressed by the replacement rate, and to the assumption that the average mortality of calves, yearlings and dairy cows is also exogenous. The replacement rate is given by the farm itself, whereas average mortality figures are taken from ASG (2003). Before running the optimisation model the average number of yearlings and calves per dairy cows are calculated from the replacement rate and the mortality rates.

3.5 Costs and benefits of livestock

The costs of livestock include such categories as cattle maintenance, milk recording, health care, etc. These costs are listed and quantified in ASG (2003). Another cost category is the renting of milk quota. The benefits of livestock include the sales of milk and cattle, and letting of milk quota.

3.6 Labour demands

The main activities included in labour demand for cattle are milking dairy cows and cleaning stables. The time required for different activities is given by Pelser (1988).

4 Fodder accounting and land use

4.1 Introduction

The fodder and land use module describes the production, purchase and sales of fodder, as well as other aspects of land use such as the presence of agri-environment schemes.

Fodder production and land use is one of the most complex elements in FIONA as the model needs to take into account such aspects as fertilisation, moment of harvesting or cutting, fodder type and growing time. Furthermore, the model distinguishes land *use* types from land *cover* types (see Section 2.3.3).

4.2 Fodder production

Fodder production is specified for each of the following properties:
- The farm for which it is produced;
- The type of the fodder;
- The land use type where it comes from;
- The intensity of the land use;
- The harvesting period when it was harvested, mown or grazed;
- The cattle type for which it was produced.

Almost all fodder types can be yielded by only one land use type and vice versa. For instance, grazed grass can only be yielded by grazing grass, and maize can only be yielded by harvesting maize. The only exception to this rule is hay from land with an extended mowing date. There are four different land use types that yield this fodder type, and each land use type has a different mowing date.

The current version of FIONA distinguishes ten different levels of intensity of land use. So far, the intensity levels only differ in fertiliser input, but future versions of the model can include additional characteristics. For grass all intensity levels are available, whereas for arable crops there is only one.

The harvesting period indicates when fodder is produced. The model distinguishes harvesting periods from feeding periods so that feeding crops harvested in one period can be supplied in another period. Grass can be harvested in all periods throughout the growing season, whereas arable crops can be harvested in late September only.

The amount of fodder produced depends on the fodder type only. Because arable crops have only one intensity level there is no need yet to include different production levels for these crops. On the other hand, because grass can be grown in several intensity levels, the model needs to take the difference in productivity between grasslands of different intensity levels into account. This can be done by either assuming that extensive grasslands have smaller cuts, or by assuming that extensive grasslands need more time to accumulate sufficient dry matter for a decent cut. Because grass is generally mown or grazed at particular cut sizes, FIONA does the latter. Each combination of grass land use types and intensity levels has its own amount of time needed to produce a given cut size, expressed as growing days. Input data on the number of of growing days needed per land use type and intensity level are taken from Asijee

(1993). Using the growing days data, FIONA calculates and allocates grass production by means of an extensive grass management calendar as described in Section 4.3.

The cattle type for which the fodder is produced is relevant for grazed grass and for hay from agri-environment schemes. Because it is generally very time and labour consuming to graze dairy cattle on field plots, FIONA assumes that production of grazed grass for productive dairy cows can only take place on home plots. Furthermore, because hay from agri-environment schemes has a very poor quality, many farms may prefer not to give this type of fodder to productive diary cows. FIONA should, however, be able to take these considerations into account. To be sure, the model offers the possibility to either allow or disallow particular combinations of fodder type and cattle type, such as giving hay from agri-environment land to dairy cattle.

4.3   Allocation of land use types and land cover types

FIONA allocates land use types in different intensities over plots and harvesting periods in order to produce enough fodder for the cattle. In order to provide enough space for the land use types, the model also allocates the appropriate land cover types over the plots. In doing so, the model takes into account the following factors:
- The size of the plot;
- The fact that each land use type can be allocated in one land cover type only;
- The amount of time needed to grow a sufficiently large yield from the land use type;
- The cattle type for which the fodder is intended.

Naturally, the sum of the areas of all land cover types in a given plot cannot exceed the surface area of the plot. Furthermore, the sum of the areas of the land use types belonging to a particular land cover type in one period cannot exceed the surface area of that land cover type. For instance, a plot of 10 ha can be covered by, say, 6 ha grassland and 4 ha arable land. Furthermore, within the grassland area, the farmer may choose to mow 3 ha for silage in early June, and let young cattle graze in that same period on the remaining 3 ha. The 4 ha arable land cannot be used, except for when it is harvested in late September.

Producing fodder, however, will in most cases take longer than a single harvesting period or feeding period. For instance, grass for silage is generally mown when about 3500 kg of grass per hectare is available. Now, suppose we need to have such an amount available by, say, the end of May at a nitrogen input of 40 kg per ha per cut. In that case, the grass must be allowed to grow (i.e., no grazing or mowing is allowed) for about 36 days before it can be mown. Because this is longer than most harvesting periods, the area that is supposed to be mown by the end of May must be kept free of mowing and grazing not just during the last harvesting period in May, but also in a number of other harvesting periods in May and April. In other words, for each hectare of a particular land use type of some intensity in some harvesting period, a given amount of growing days are needed in several feeding periods. In this case, because both April and May are split up into two harvesting periods, the growing days needed have to come from the two harvesting periods in May and from the second harvesting period in April (Table 2).

Table 2: Growing days needed per hectare from each harvesting period to grow 3500 kg/ha of grass by the end of May under a nitrogen input of 40 kg/ha

Month	April		May	
First day of period	1	16	1	16
Number of days in period	15	15	15	16
Growing days needed to have 3500 kg/ha by the end of May	0	5	15	16

The total growing time needed for a particular land use type in a particular harvesting period is equal to the number of days needed per hectare for that land use type times its surface area. On the other hand, the growing time available in each period from the area of land cover where the land use type is allocated is equal to the length of that period time the surface area of the land use type. Hence, growing time is expressed in hectare days: days times hectares.

To illustrate this, suppose we have a plot where 6 ha grassland is located and we wish to mow this piece of grassland at 3500 kg/ha by the end of May. The total growing time needed for this cut is 6 ha $\times$ 36 days = 216 hectare days. Hence, we need all hectare days available from the periods in May, and some hectare days from the last period of April (Table 3).

Table 3: Total growing days needed from each harvesting period to grow 3500 kg/ha of grass by the end of May under a nitrogen input of 40 kg/ha on a plot of 6 ha

Month	April		May	
First day of period	1	16	1	16
Number of hectare days in period	90	90	90	96
Hectare days needed from this period	0	30	90	96

In practice this means that the grassland in the plot cannot be used at all in May because the grass should be allowed to grow. For April, however, the real-world interpretation is more difficult. It should mean that the entire 6 ha of the grassland on this plot cannot be used for a third of the second harvesting period in April. It could, however, also mean that 2 ha are used for the entire harvesting period. This problem stems from the fact that feeding and harvesting periods will never perfectly match the number of growing days needed for a particular land use type.

There are at least two ways to combat this problem. The first would be to round the number of growing days to full harvesting periods. In this case it would mean that we would round the current 36 growing days down to 31 days (the two periods in May) or up to 46 days (the two periods in May plus the second period in April). This measure would eliminate the problem altogether, but it would also cause a substantial difference between the assumed and the theoretical number of growing days needed. In some cases this difference could become as large as 6 or 7 days, which is about a quarter to a third of the amount of growing days needed for some land use types. Therefore, if the model is to be corrected in this way, it should be accompanied by a correction of the fodder yield to reflect the shorter or longer growing period. An easier option would be to shorten the feeding periods and harvesting periods. This will not eliminate the problem entirely, but it will increase the accuracy of the model because it will increase the number of harvesting periods where all growing time is needed, whereas it reduces the length of the one period where only part of the available growing time is needed.

The cattle type for which the land use type is intended is relevant for the same reason as why it is relevant for the fodder type (see Section 4.2). To avoid grazed grass from field plots being given to productive dairy cows, the area of the land use type that would do so is set to zero.

4.4 Stocking, production and supply of fodder

With regard to stocking of fodder, FIONA distinguishes three types:
- Fodder types that are directly given to cattle after production;
- Fodder types that are stocked after production to be given to cattle at a later time;
- Fodder types that are not produced at all.

The first category refers to grazed fodder types. They are not stocked, so supply of these fodder types in a given feeding period cannot exceed their production in the corresponding harvesting period.

The second category includes such fodder types as grass silage and arable crops. For these fodder types, supply and sales over all periods cannot exceed production plus purchases. Furthermore, total production of these fodder types cannot exceed the stocking capacity of the farm. The stocking capacity is endogenous to the model, but it can of course also be fixed.

The last category includes fodder types that can only be purchased, i.e. concentrates. As concentrates are easier to transport and purchase than roughage such as maize, there are no restrictions with regard to the stocking capacity of concentrates.

4.5 Fodder sales and purchases

Fodder types that can be purchased are in principle available in any intensity level or harvesting period allowed in the model. So far, however, all such fodder types (i.e., all fodder types except grass and hay) have only one intensity level and harvesting period.

For technical reasons, supply of concentrates is also specified by land use type, intensity, harvesting period and cattle type. Not doing so would require expressing supply of concentrates in a separate variable, which would make the model unnecessarily complex. Therefore, the only concentrates available come from a hypothetical land use type ('purchasing'), one intensity level, and one harvesting period.

Because all prices are exogenous in farm models such as FIONA, these models have the drawback that they cannot take higher-scale market effects into account. Therefore, users should be cautious in interpreting the model results if they imply large amounts of fodder sold or bought. After all, if model runs for large groups of farms show similar results for a large proportion of the population, one would expect some price effects. This problem can be restricted somewhat by adding an upper bound to the fraction of fodder produced that is sold on the market.

4.6 Fodder quality

In theory, the quality of fodder depends on a wide range of factors such as fertilisation, the moment of harvesting, cutting or grazing, and the amount of time between two cuts. However, because it is not possible to determine fodder quality endogenously in a linear model, fodder quality is given per fodder type, and for grass it also varies per harvesting period. All parameter values for fodder quality are taken from ASG (2003).

4.7   Costs and benefits of fodder production and land use

Costs of fodder production and land use
Costs of fodder production and land use consist of the following categories:
- Costs of maintenance of land cover types
- Costs of harvesting, mowing, grazing and ensiling;
- Costs of purchase of fodder;
- Costs of maintaining stocks of fodder

Maintenance costs of land cover types
So far the only land cover type that needs maintenance in the model is grassland. It is assumed that each year a fraction of the grassland is renewed.

Costs of harvesting, mowing, grazing and ensiling
Costs of harvesting arable land are included on a per hectare basis and are taken from ASG (2003). Costs of mowing, grazing and ensiling of grass depend partly on whether it is done by contract workers or the farmer him or herself. The farmer can save his or her own labour by contracting out work, but it is also more expensive. All costs are taken from ASG (2003).

Costs of fodder purchase
Fodder prices are taken from ASG (2003).

Costs of fodder stocks
Because the fodder stock capacity of the farm restricts the amount of fodder that can be produced, the model would presumably tend to increase this capacity. In some cases the user may prefer to keep this capacity exogenous, and even if the model is allowed to determine fodder stock capacity endogenously, the capacity can only be raised at certain costs. The costs of maintaining fodder stock capacity are taken from ASG (2003).

Benefits of fodder production and land use
The benefits of fodder production and land use consist of fodder sales and subsidies for particular land use and land cover types.

Subsidies for land use and land cover types
Direct payments and subsidies for nature management can either be ascribed to land use types or land cover types. Considerations that determine how these subsidies are ascribed include:
- Does the payment support a particular type of land cover?
- Does the payment support an act of some sort?
- Does the subject of payment change over the year or is it a constant?

For instance, some agri-environment contracts are best included as land use types, whereas other are best included as land cover types. Botanic management generally restricts the input of nutrients and pesticides, and the maximum amount of grazing and mowing, over the entire year. Therefore, they are best included as a separate land cover type that only allows for extensive land use types such as grazing with low input of fertilizer. On the other hand, the most important element of meadow bird agreements is the extended mowing date. Under a meadow bird agreement, farmers delay their first cut to some date in June, after which they can use the land as they please. Therefore, these agreements are best included as a land use type that can be allocated to the land cover type 'grassland'.

For direct payments the matter is slightly more ambiguous. For instance, as the maize premium depends on the surface area of maize land, the most obvious way to include this subsidy would be to ascribe it to the land cover type 'maize land', as is currently the case in FIONA. On the other hand, future versions of FIONA may merge all different types of arable land into one type. Because the number of growing days of each arable crop is such that its growing time covers the entire growing season anyway, the maize premium could also be ascribed to the land use type 'harvesting maize'.

4.8   Labour demands

Labour demands with regard to land use include the following categories:
- Maintenance of land cover types;
- Harvesting, mowing and ensiling.

Maintenance of land cover types

So far, grassland is the only land cover type that needs maintenance. The activities that require labour input include dragging cow pats, rolling of loose parcels, mowing of bunches and suppressing of moles (Vink and Wolbers 1997). Furthermore, each year a fraction of the grassland is renewed. In FIONA this job can either be done with own labour (ploughing and harrowing) combined with contracted work (sowing, chemical pest control) or entirely with contracted work.

Harvesting, mowing and ensiling

Labour demand for mowing, grazing and ensiling of grass depend partly on whether it is done by contract workers or the farmer him or herself. The farmer can save his or her own labour by contracting out work, but it is also more expensive (Vink and Wolbers 1997).

5 Soil nutrients

5.1 Introduction

The nutrient module in FIONA describes the nutrient cycle on the farm, including nutrient demand for fodder production, nutrient supply from the cattle, purchase of fertilizer, background deposition of nutrients and removal of manure from the farm. FIONA considers only the nitrogen cycle. In compliance with good agricultural practice farmers have to abide by environmental legislation. For this a special fertilizer legislation module is included in FIONA.

5.2 Nutrient balance

Nitrogen demands are determined in the fodder and land use module and specified per plot, land cover type and feeding period. In calculating these demands, FIONA assumes that all nutrients required must be supplied at the start of the growing period. In the nutrient module, these demands are met by supply of manure and fertilizers.

Whereas fertilizer nitrogen is readily available after supply, nitrogen in manure is released only gradually over the next few months, depending on the type of soil and application method. Therefore, nitrogen supply in a given plot in a given feeding period depends not only on the amount of fertilizer given in that feeding period, but also on the amount of animal manure given in previous periods and the amount of nitrogen released from this periods in the current period. Lastly, background deposition of nitrogen is included in the supply of nitrogen.

The nitrate content of animal manure is taken from Vink and Wolbers (1997), and corrected for volatilization by stable emission after Berentsen (1999). The background deposition comes from MNP (2005).

5.3 Manure stocks and application

FIONA calculates the amount of manure stocked in each feeding period from the amount of manure in stock in the previous period, and manure application, removal and manure production in the current period. Furthermore, the model calculates for each farm the maximum amount of manure in stock over the year as well as the largest increase in stocked manure over the year. The manure stock capacity must be larger than the largest amount plus the largest increase. The manure stock capacity must also be larger than the fixed levels per animal place in the barn set by the Dutch manure legislation. Furthermore, there are rules for the maximum amount of nitrogen from animal sources (manure) allowed to be spread out over the land and rules for the total amount of nitrogen. The (fixed) standards for concentrations of nitrogen in manure, standards for nitrogen uptake by crops and so on are given by DR (2006a) for this purpose.

5.4 Benefits and costs

There are no benefits from nutrients in the current version of FIONA. Costs from nutrients include the costs of stocking manure and manure removal, manure and fertiliser application

and fertiliser purchase. These costs are taken from ASG (2003) and from DR (2006a). The costs of stocking manure and manure removal are determined by Dutch legislation. The costs of stocking manure are directly related to stable capacity and are therefore treated as exogenous.

5.5   Labour demand

Labour is needed for applying nutrients to crops. Animal manure can be applied in several levels of intensity, where each level differs in the amount of manure spread per hectare and in the amount of labour needed. Therefore, animal manure application is expressed in hectares in a particular plot and a particular feeding period. Hence, labour demand for animal manure application is expressed in the number of hours per hectare for each manure application level. In most cases, however, animal manure is applied by contract workers because of the special equipment that is needed to inject the manure directly into the soil. Because fertilizer application is expressed in kilograms of nitrogen, labour demand for this activity is expressed in hours per kilogram.

6 Labour

6.1 Introduction

The labour module calculates the labour demand for each feeding period, which depends on the labour demand in each module plus labour needed for general purposes that cannot be ascribed to any specific module. With regard to labour supply, FIONA includes a restriction on the average working week over the entire year as well as a restriction on the working week during peek periods.

6.2 Labour demand

Each module in FIONA has a variable for labour demand that expresses the amount of labour needed in each feeding period for that particular module. In the labour module, these demands are collected in order to calculate the total amount of labour needed in each feeding period for the entire farm.

Besides labour demand from specific modules, each farm must also set aside working hours for general purposes such as administration, supervision, and maintenance of fixed assets. The model is free in determining when these labour hours are spent exactly, as long as they sum up to a prespecified minimum.

6.3 Labour supply

Labour demands are met by the labour that is already available on the farm plus labour hired from outside the farm. FIONA applies two restrictions to balance supply and demand, where one refers to the average labour input and the other to the labour input during peek periods.

The first restriction demands that the total amount of labour needed over the entire year does not exceed the total labour endowment of the farm, plus the total amount of labour hired, minus the total amount of labour letted (although this last variable will be set to zero in most applications of FIONA). The total labour endowment on the farm is equal to:
- the number of workers on the farm, expressed in VAK[7]
- times the average working week of a worker, in hours
- times the number of weeks in a year (52).

This restriction only restricts the average labour input, allowing for working weeks of extreme magnitude. To prevent such extremes, FIONA also includes a second restriction to the input of labour which demands that the input in each feeding period does not exceed the maximum labour input allowed for that period plus the amount of labour hired in that period minus the amount of labour letted in that period. The maximum labour input in each feeding period is based on the maximum length of a working week during peek periods, which is a farm-specific input parameter.

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[7] Volwaardige Arbeids Kracht (full labour force), a measure to indicate the number of workers corrected for their ability to work. The measure differs from fte in the sense that fte is the number of workers corrected for the length of their working week.

7 State of affairs and wish list

7.1 Current developments

FIONA is currently being extended in order to include nature management activities under the Subsidieregeling Natuurbeheer (DR 2006b). For this purpose, the following elements are introduced to the model:
- Husbandry of such cattle types as suckler cows and sheep;
- Stand grazing (conventional as well as for purposes of nature management);
- The new Dutch manure policy;
- Influence of groundwater levels on crop production.

7.2 Weak spots and cautions for use and interpretation

No model is perfect, and neither is FIONA. Some imperfections of the model are symptomatic for the model type of FIONA and therefore unavoidable. Others may merit close attention in future development of the model.

Model runs versus farmer decisions
One should take caution interpreting FIONA results as predictions of farmer behaviour. FIONA calculates the short-term farming strategy that maximizes farm income, assuming away uncertainties, individual preferences of farmers and psychological factors. In reality, however, these factors are likely to play an important role in farmer decisions. Farmers may participate less in agri-environment schemes than predicted, because of uncertainty in the reduction of fodder production, or because they have a personal dislike of government meddling on their land. On the other hand, personal affection for nature may lead farmers to participate more in agri-environment schemes than is financially optimal. These problems can hardly be tackled and are simply the consequence of using a quantitative, economic model.

Exogenous prices
Being a farm-level linear programming model, FIONA assumes all prices to be exogenous. This assumption should not be problematic for single-farm analyses, but when large numbers of farms are analysed, for instance in analyses of agri-environment schemes as is done in Schrijver et al. (2005), one should be wary of possible effects on product and factor markets. For instance, if the model predicts large increases in purchases of fodder crops, prices of these crops are likely to rise.

This problem is typical for models formulated at farm level, as one cannot expect a single farm to influence national or even regional crop prices. It may be tackled with ad-hoc measures such as restrictions on the amount of fodder purchased. A better way to deal with this problem, however, would be to improve the communication between FIONA and models of regional or national factor and product markets such as DRAM (Helming 2005).

7.3 Possible future developments

Besides changes that may be necessary for future projects, we recommend the following directions for further development of FIONA.

Further steps in quality management

Providing a description of FIONA, as is done in this report, is but one step in the further improvement of the quality of the model. Further steps should at least include an analysis of FIONA's sensitivity to several parameter values, and a validation of the model results. Additionally, a technical review of the model code may identify flaws and inefficiencies in the model code, and provide suggestions to improve the quality of the model.

Analysis of mosaic management

Meadow bird conservation may benefit strongly from co-ordination between the farms that participate in it through extended mowing dates and such. Ideally, such co-ordination ensures that a sufficient variety of vegetation (i.e., a mosaic) is maintained throughout a large part of summer. FIONA may be helpful in the development of cost-effective spatial strategies of mosaic management. Therefore, it would be interesting to explore the possibilities to adapt the model such that it can analyse such spatial nature management strategies.

Communication with economic models on higher spatial scales

Because FIONA is designed for analyses on farm scale, input and output prices are necessarily assumed constant. According to the analysis and the scenarios involved, however, we may expect prices to vary over time, causing exogenous shocks to the farm under consideration. On the other hand, if FIONA predicts that a very large number of farms will change their inputs in roughly the same manner, e.g. by buying more and producing less fodder crops, we can expect price effects that make the constant prices assumption very implausible. To be able to analyse such effects, a connection needs to be made between FIONA on one hand and higher-scale models on the other hand. The agricultural sector model DRAM (Helming 2005) is a particularly promising candidate for such communication.

Communication with ecological models

Although FIONA can in principle be applied to a wide range of farm management questions, agricultural nature management will probably remain its main focus. Therefore, closer collaboration with ecological models is also needed to make sure that the ecological knowledge used in FIONA is consistent with the current state of the art, and with ecological models currently used at the Netherlands Environmental Assessment Agency. One such model that should be considered is MOVE (de Heer et al. 2000).

Recommendations in the FIONA todo list

The FIONA GAMS model includes a file (fiona.todo) that lists small changes that may be necessary to the model. This list probably goes into too much detail to be included in this report, but the points made in this file nevertheless need to be looked into.

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Appendix 1   : Index of terms

WOt-onderzoek

Verschenen documenten in de reeks Werkdocumenten van de Wettelijke Onderzoekstaken Natuur & Milieu – vanaf mei 2005

Werkdocumenten zijn verkrijgbaar bij het secretariaat van Unit Wettelijke Onderzoekstaken Natuur & Milieu, Lumengebouw, te Wageningen.

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De werkdocumenten zijn ook te downloaden via de WOt-website www.wotnatuurenmilieu.wur.nl

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