Protocol for input and output data of the simulation models NTEGRATE, GRASMOD and the Dairy Farming Model

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The Research Institute for Agrobiology and Soil Fertility (AB-DLO) is part of the Agricultural Research Department (DLO) of the Dutch Ministry of Agriculture, Nature Management and Fisheries (LNV).

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AB-DLO carries out both fundamental strategic and application-oriented research. It is positioned between the fundamental basic research carried out by universities and the practically-oriented research done by research stations.

AB-DLO's research is targeted at:
- promoting the sustainability and quality of crop production;
- the sustainable use of land, water and energy;
- the development of agricultural systems within the framework of multifunctional land use.

This research contributes to the solution of problems concerning the efficient management of substance and energy flows in agro-production chains, the ecologisation of primary production, the regional and global provision of food, and the multifunctional use of rural areas.

The research is divided among three themes:
- Quality: the quality of crop production and crop products.
- Environment: minimisation of the environmental effects of agricultural activities in soil, air and water.
- Sustainable agriculture: development of farming systems within frameworks of multifunctional land use.

AB-DLO's core fields of expertise are plant physiology, soil biology, soil chemistry and soil physics, nutrient management, crop and weed ecology, grassland science and agrosystems research.

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Table of Contents

1. Introduction

In the COGANOG project (Controlling *G*aseous *N*itrogen *O*xide emissions from *G*rassland Farming Systems) a number of European research institutes cooperate in improving our understanding of the controlling factors of the N_2O and NO_x emissions from grassland farming systems in Europe (Anonymous, 1997). Field measurements will be combined with simulation techniques to achieve this goal. Models are used in the COGANOG project (1) to increase our knowledge of the relative importance of the different processes that determine the emissions of N_2O and NO_x and (2) to provide information on the risks of N_2O and NO_x emissions as a function of site characteristics and management practices. The field measurements will be used for parameterisation and validation of the assumptions underlying the model simulations. With the results of the simulations, sustainable management options can be identified with minimal N_2O and NO_x emissions.

AB-DLO is responsible for modelling the N_2O and NO_x emissions from managed grassland systems in the COGANOG-project. Two models will be used: NTEGRATE for the simulation of the emissions at the field scale and the Dairy Farming Model for the simulation of the emissions at the farm level. At the first meeting of the COGANOG-project (Haren, 7-8 February 1997) it has been agreed that AB-DLO will provide a protocol for the collection of additional grassland data based on the input/output data of the models. This report gives the input requirements and the output data of NTEGRATE and the Dairy Farming Model. This protocol of input and output data is based on the model version of NTEGRATE described by Vellinga *et al.* (1997) and on the model version of the Dairy Farming Model described by Van de Ven (1996). Specific information on the input/output of N_2O and NO_x emissions are not described in this report, because the models, in their present state, have not yet been adapted to calculate these emissions. This will be done during the course of the project.

2. Use of modelling in the COGANOG project

2.1. Relation between the models

NTEGRATE is a dynamic model that calculates daily changes in the major state variables of a managed grassland system at the field scale. Daily weather data, detailed soil characteristics, attributes of grass and animal species, and information on management practices are required. The Dairy Farming Model is an optimisation model to achieve both environmental and economic goals at a satisfactory level. By an iterative procedure the 'best' production technique at the farm level is identified for a given set of goals and constraints. The inputs for the Dairy Farming Model are mean annual data on crop/animal production techniques together with some economic and technical data. The data on the production techniques are calculated by technical coefficient generators (TCG), of which GRASMOD provides the input/output relations of grassland farming systems. The input for GRASMOD consists of empirical relations of annual data, which apply to a specific site in an average year. Examples are average annual dry matter yield as a function of nitrogen supply and average annual denitrification as a function of nitrate leaching. GRASMOD and the Dairy Farming Model can only be used for management decisions that are being made over a period of one or more years, whereas NTEGRATE can be used for daily management, e.g. by taking account of daily weather conditions.

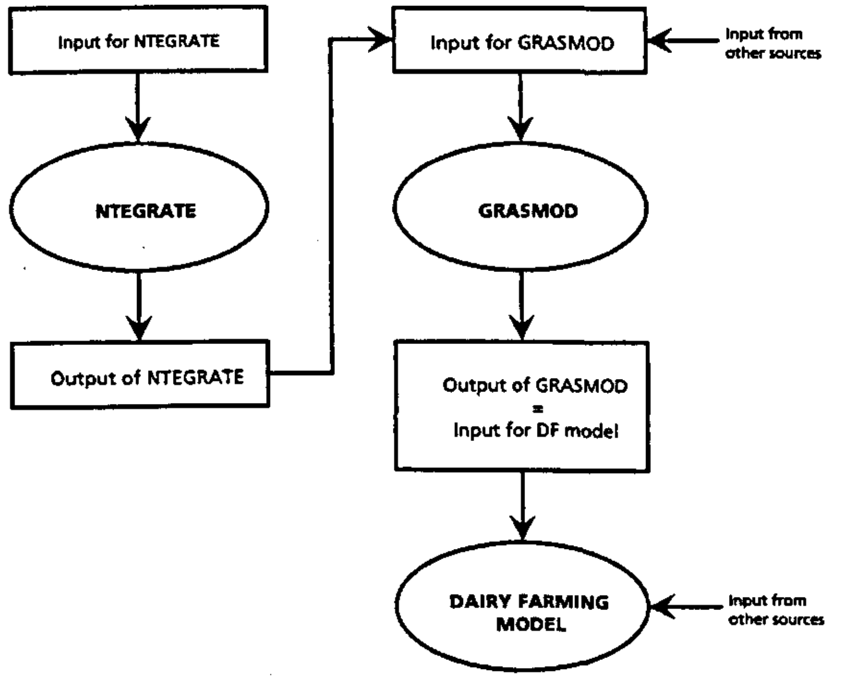

Figure 1. Relationship between NTEGRATE, GRASMOD and the Dairy Farming Model as used in the COGANOG project

In the COGANOG project annual values will be derived from calculations with NTEGRATE and these will be used as input for GRASMOD and subsequently the Dairy Farming Model (see Figure 1). Calculations with NTEGRATE are necessary because up to now GRASMOD and the Dairy Farming Model are only parameterised for sandy soils in The Netherlands with an average groundwater table and because empirical relations between N_2O and NO_x emissions and site characteristics and management practices have not yet been established. Multiple runs with NTEGRATE are needed to determine the empirical relations for GRASMOD. E.g. to find the relation between average annual dry matter yield and annual nitrogen supply for a given site and management, many combinations of year and nitrogen fertilisation level are necessary. Not all input requirements for GRASMOD can be provided by NTEGRATE, which means that some data must still be derived from other sources.

2.2. Timing of data supply

For the simulations in the COGANOG project data are needed to provide input data for the models and to test the simulation results. Default values for the input data, which apply to all situations, can not be used due to large differences in climate, soil type, management and economic conditions of the countries participating in the project. Furthermore, the relative importance of the input data for the emissions of N_2O and NO_x cannot be given at this moment because the calculations concerning N_2O and NO_x are not yet included in the models and the sensitivity of the model to its inputs is not constant. It varies with the site characteristics, which differ among the various countries participating in the project. To simulate the emissions of N_2O and NO_x at the field scale and at the farm level with adequate accuracy, all data should be determined by each participant for each site, production technique and grassland farming system under consideration in the COGANOG project. For the use of NTEGRATE some of these data may be collected in the field, additionally to the measurements on N_2O and NO_x (Corré, 1997). The other data should be gathered by using other sources, such as literature, expert knowledge, etc. For the Dairy Farming Model data collection consists of farm surveys, literature, expert knowledge and other sources.

In the technical annex of the COGANOG project a time table is given of all tasks during the whole project, which determines the timing of the data supply for the simulations (see Figure 1 on page 29 of the technical annex). Testing NTEGRATE against the field measurements of the monitoring experiments starts in autumn 1997. All relevant data at the field scale, available at that time, should be supplied by September 1997 by the participants involved in these measurements (task 1.2), including the data set from The Netherlands. The monitoring experiments continue until the last year of the project and an update of the field data every 3 months is sufficient for the simulations with NTEGRATE. Measurements that are related to the field campaigns (task 1.3), the stable isotopes compositions (task 2) and the factors controlling N_2O and NO_x (task 3) can be supplied as soon as they become available after experimentation. These data will be used to verify specific assumptions underlying the calculations with NTEGRATE. In the summer of 1998 NTEGRATE will be used to provide input for GRASMOD and the Dairy Farming Model for eight well-defined European grassland farming systems. The data required for these calculations should be supplied in April 1998, including those related to the Dairy Farming Model and GRASMOD.

3. NTEGRATE

3.1. Description of the model

NTEGRATE describes the water, carbon and nitrogen balance of a soil-grass vegetation system under conditions of cutting and grazing. It has been developed by a number of Dutch research institutes involved in N cycling and grassland management. A technical document (in Dutch) will be published in the 2nd half of 1997 (Vellinga et al., 1997).

Basically, NTEGRATE consists of 5 submodels which communicate through a main programme (see Figure 2). Input data are supplied by filling in a questionnaire (via a user interface) and by a number of databases. The grassland management module (1) consists of a number of algorithms related to the grazing system and the nitrogen and carbon economy of dairy cows. Excretion of carbon and nitrogen by faeces and urine is calculated and urine patches are simulated separately with respect to grass growth and nitrogen balance in the soil. A fertiliser recommendation module (2), which is not yet implemented, will calculate a recommendation for the nitrogen fertiliser application based on the expected supply and the demand for mineral nitrogen in a growing period. Risks of excessive loss of nitrogen to the environment due to high fertilisation and (too) low grass production at low fertilisation will be calculated and can be weighed to determine the recommendation. The soil water balance module (3) describes the one-dimensional saturated and unsaturated soil moisture flow in a heterogeneous soil profile. The unsaturated flow is modelled based upon Darcy's law and the continuity equation. The terms of the water balance considered are: actual evapotranspiration, actual infiltration (precipitation minus interception and runoff), lateral transport of water to or from the soil profile and transport of water through the bottom layer of the soil profile. The distribution of soil temperature with depth is also calculated. The soil nitrogen balance module (4) simulates the carbon and nitrogen turnover processes in the soil. The most important transformation processes are: decomposition of soil organic matter, mineralisation/immobilisation, nitrification and denitrification. Losses of nitrogen from the soil profile occur by leaching of mineral nitrogen and dissolved organic matter to ground and surface waters, denitrification and NH_3 volatilisation. In NTEGRATE denitrification covers both N_2 and N_2O production, but the ratio of N_2 to N_2O (and NO_x) is not yet calculated. The grass growth module (5) describes the carbon and nitrogen dynamics of a grass sward. Total dry matter production and nitrogen uptake is calculated and partitioned among roots, leaves and stems/sheaths. A distinction is made between stubble and harvestable parts in the above-ground biomass. Furthermore, the turnover rates of all plant compartments are calculated and the dead plant material is transferred to the pool of organic matter in the soil.

Results of a simulation run are presented in balance sheets, which contain the values of the main rate variables accumulated per growing period, and by creating a number of files with the results on a daily basis.

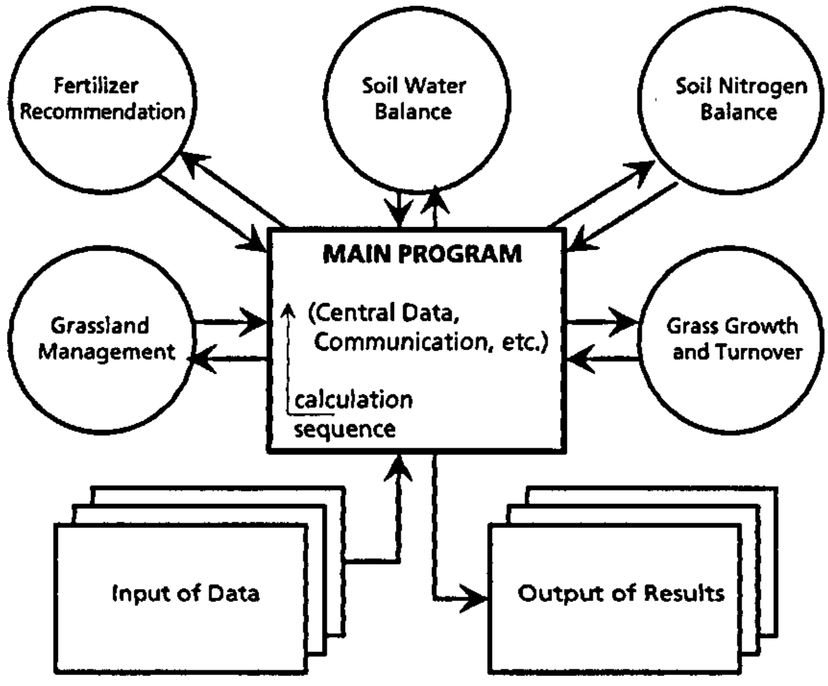

Figure 2. Outline of the modules used in NTEGRATE and the calculation sequence (adapted from the technical document, Vellinga *et al.*, 1997)

3.2. Input requirements of NTEGRATE

A list with the input requirements is given in Appendix I. Most input data are supplied through a questionnaire (in Dutch) and via a number of databases. It is difficult at this stage to provide a ranking of the input data with respect to their relevance to the COGANOG project (as explained in 2.2). It is therefore proposed that each participant in the project examines the list of input requirements and determines the values of all the necessary input data for each site under consideration in the project in their country. A selection of these can be measured in the course of the project in combination with the measurements on N_2O and NO_x. More information on these input requirements is given in the protocol "Uniform and Standardised Recording of Soil, Crop and Climate Data within the COGANOG Project" (Corré, 1997).

3.3. Output of NTEGRATE

For each day state and rate variables of the modelled processes can be printed to an output file. A summary of the calculated results is also given by balance sheets which provide the main components of the nitrogen and carbon balance in the animals and the vegetation and the soil nitrogen and soil water balance, accumulated per growing period. The variables listed in Appendix II are a selection of all possible variables and comprise the most important data to test the results of NTEGRATE with field measurements. Again, a selection of them can be measured during the project in combination with the N_2O and NO_x measurements and information on these output variables is given in the protocol of Corré (1997).

4. The Dairy Farming Model

4.1. Description of the model

4.1.1. The Dairy Farming Model

The Dairy Farming Model was developed to explore development options and identify promising techniques in dairy farming from both the environmental and economic point of view in the context of integrated dairy farming.

On a dairy farm several crops are grown, such as grass, maize and fodder beet. Grass can be cultivated in many ways, which can be characterised by input-output coefficients. It depends on the goals to be optimised which characteristics need to be quantified. The characteristics of the production techniques for grass are listed in the first column of Figure 3. They represent the essential elements for development of environmentally-sound dairy farming. For each of these characteristics several values can be set by the user of the model.

The input-output table for grass production techniques should be quantified consistently for the whole range of possibilities. Therefore, technical coefficient generators (TCG models) have been developed. The values of inputs and outputs for a production technique are called technical coefficients. GRASMOD is a TCG that calculates inputs and outputs for a wide range of grass production and utilisation techniques. Inputs ('+' in the input-output table) are land and fertiliser for instance and outputs ('-' in the input-output table) are forage and nitrate leaching (Figure 3). Other crops such as maize and fodder beet can also be included, but are of minor importance in this phase of the COGANOG project. The structure of the TCG and the data used in the model are explained below.

In addition to the input-output table for crop production techniques, some other technical and economic data are required. These are supplied to the model by means of a data file (Figure 3). Inputs and outputs for cattle are taken into account partly in GRASMOD and partly in the data file. For cattle, forage is an input and milk and meat are outputs. As optimisation technique *I*nteractive *M*ultiple *G*oal *L*inear *P*rogramming is chosen. The IMGLP model integrates the input-output table of the production techniques and the data file in one optimisation matrix. The matrix includes the goals, i.e. economic, production-oriented and environmental, and constraints that the dairy farming system has to meet.

In successive optimisation rounds the restrictions on the goals are tightened and the set of feasible dairy farming systems is reduced step by step.

4.1.2. GRASMOD, a TCG for grassland management

GRASMOD calculates the influence of grassland management on nutrient utilisation and emission to the environment. It is an empirical model, based on data from experiments, literature and experts. Inputs and outputs of a range of grassland management systems are quantified systematically and they form the basis for optimisation applied to dairy farming in a later stage.

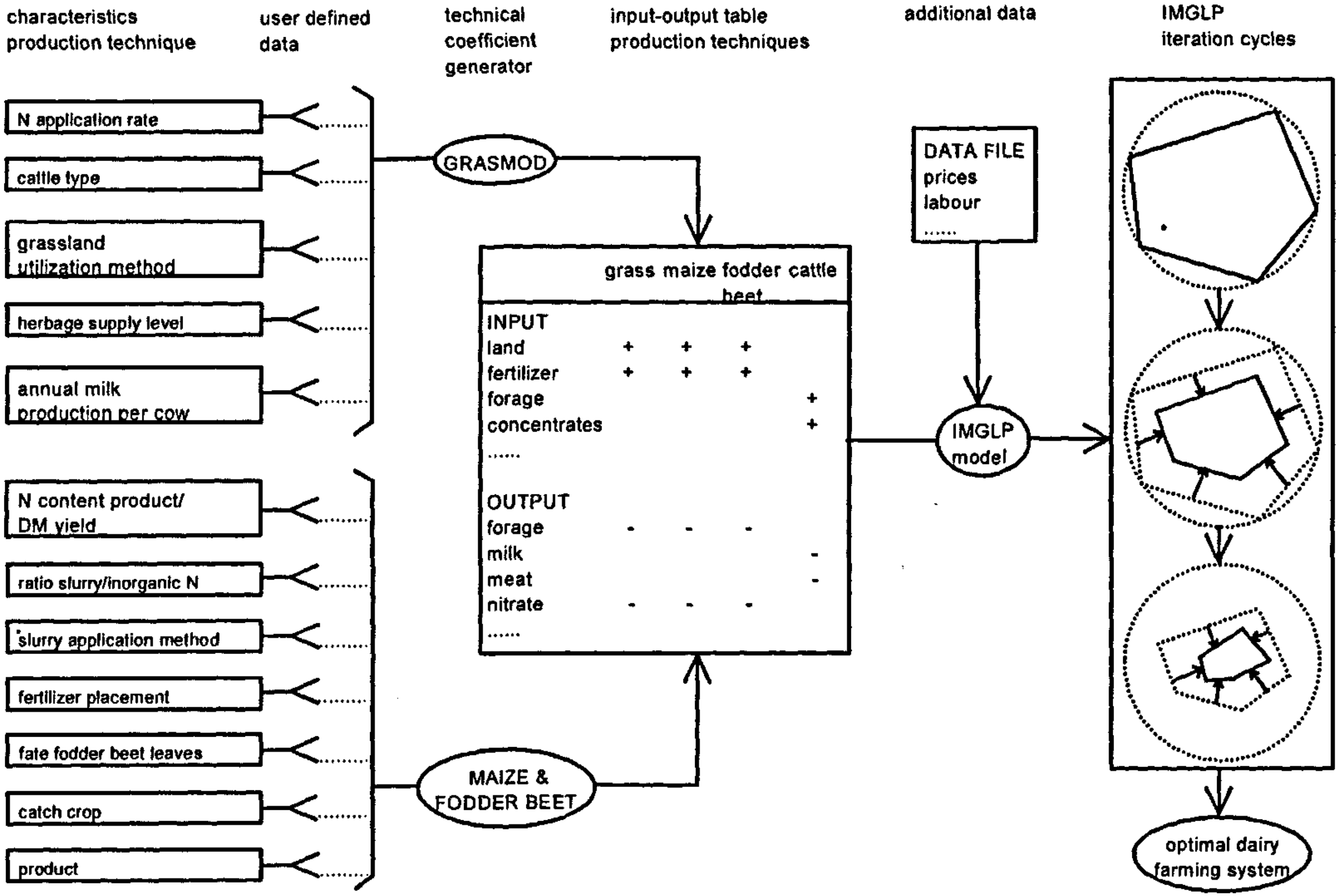

Figure 3. Schematic presentation of the Dairy Farming Model used for optimisation of dairy farming systems

Starting points

* All calculations are executed per unit land area (not per farm) on an annual basis.
* It is valid for grassland on well-drained sandy soils, with an average water holding capacity.
* It is assumed that all operations belonging to a well-managed grassland are executed, although those are not explicitly defined in this model.

Inputs and outputs for a wide range of grass production techniques can be calculated. GRASMOD covers the following characteristics (Figure 3):

* grassland utilisation method (day and night grazing, day grazing only with the supply of maize silage, zero grazing with or without maize silage, cutting for conservation);
* animal type (dairy cow, calf or yearling);
* N fertiliser application. In GRASMOD it is assumed that all N is applied as chemical fertiliser. Later on, in the optimisation procedure this can partly be replaced by animal manure;
* herbage supply level (herbage intake as a fraction of the maximum herbage intake; the maximum herbage intake is a physiological maximum determined by milk production level. At a herbage supply level of 1.0, the diet is based on roughage. At a lower value, part of the roughage is replaced by concentrates. At high milk production levels some concentrates have to be supplied anyway to realise the required energy intake. A herbage supply level of 1.0 implies the highest possible roughage intake under the prevailing circumstances;
* annual milk production level per cow.

These systems vary in grazing losses and application of urine and faeces by grazing dairy cows and thus in net herbage production and nutrient losses to the environment. The user of the model can compose a grass production technique by selecting one value for each characteristic. The technical coefficients for that technique are calculated by running the model. First, herbage yield is derived from N application level and grassland utilisation method. Next, the stocking rate is calculated in dependence of milk production level per cow, herbage yield and additional feed supplies, such as concentrates and maize silage.

Nitrogen

The basic relation for the calculations is that between gross dry matter production and N uptake. This is influenced by the grazing/cutting regime. N taken up by the grass originates from various sources: deposition, decomposition of organic matter, fertilisers (both organic and chemical) and when grazing takes place, from urine. It is assumed that N in faeces is present in an organic form, which only becomes available for plant uptake slowly. It is not considered a separate source, but included in the soil organic N.

From experimental data was derived that N uptake from mineralisation and deposition on permanent grassland on sandy soils is about 150 kg ha^{-1} yr^{-1}. The remainder of the N uptake should be covered by fertilisation, either slurry or chemical fertilisers.

Nitrate leaching depends on fertiliser level and is derived from field experiments. Denitrification has not been modelled yet, but was set at a percentage of the nitrate losses in the rooted zone, depending on the depth of the groundwater table.

The P and K cycle were also modelled but in a less detailed way.

4.2. Input requirements of the Dairy Farming Model

4.2.1. Input requirements for GRASMOD

The parameters used in GRASMOD are listed in the file DEFAULT.INP (Appendix III.1.).
If calculations have to be executed for a specific farm, the default values can be replaced by others if they are put in a file called FARM.INP. The default values apply to a sandy soil in the Netherlands. For other sites they should be adapted to the prevailing conditions of climate, soil type and management. Therefore, all parameter values have to be checked by each participant in the COGANOG project.

In addition to this list of parameters, calculations on nutritive value and ration of dairy cows require parameters. These are partly given in the Feeding Standards and in procedures to convert the nutritive value to the units used in GRASMOD. The nutritive value with regard to both energy and protein content and the digestibility of herbage according to the Dutch protein valuation system are calculated in the subroutine FEED (Appendix III.2.).

The ration of the dairy cows is calculated, based on the nutritive value of the feed and the energy and protein requirements, in the subroutine DIET. The parameters used in these calculations are listed in Appendix III.3. Here, it also applies that all parameters have to be checked by each participant, for the same reasons mentioned earlier.

4.2.2. Input requirements for the IMGLP model

All parameters are expressed per year. Two types of input data are distinguished: those calculated by the TCGs and other input data. For grass, maize and fodder beet cultivation the TCGs supply the required input/output data for the IMGLP model. Hence, these data are outputs of the TCG and inputs for the IMGLP model. They are listed in Appendix V. If all parameters of the TCG are checked carefully, the output of the TCGs (= input for the IMGLP model) does not need additional attention. However, those that can be measured easily, may provide a check on model performance in general.

The other input data for the IMGLP model, supplied by the data file (Figure 3) have to be checked by each participant.

4.3. Output of the Dairy Farming Model

4.3.1. Output of TCG GRASMOD

Output of GRASMOD consists of two parts. One part has already been described, i.e. the part that directly supplies technical coefficients to the IMGLP model. This output is not very informative and therefore also other output is generated. The output file GRASN.DOC contains a more detailed description of each grass production technique. This set of results gives an idea of the performance of that technique. An example of output for one grass production technique is given in Appendix VI. It should be noted that the figures apply to the summer period only.

4.3.2. Output of the IMGLP model

The IMGLP model gives the optimal dairy farming system according to the goals that are optimised. An example of output is given in Table 1. Other characteristics of the dairy farming system can be calculated on request. The results presented do not refer to the grass production technique presented in Appendix VI. It should be noted that GRASMOD applies to grassland in summer only and the Dairy Farming Model to a complete farming system.

Table 1. Optimisation results for maximum labour income and minimum nitrate leaching with no restrictions, in units per ha per year in the region. All figures pertain to an average ha in the region, except N application rate, which pertains to one ha grassland.

Characteristics production system	Unit	Maximum labour income	Minimum nitrate leaching
Goal			
Labour income	Dfl	5.250	3.440
NO_3-leaching	kg N	56	14
NH_3-volatilisation	kg N	178	128
Land use			
Grass freshly fed			
Area	%	65	62
N application	kg	410	100
Grassland utilisation			
cows		zero grazing no maize	zero grazing no maize
yearlings		zero grazing	zero grazing
calves		zero grazing	zero grazing
Herbage supply level		0,80	0,80
Grass conserved			
Area	%	35	33
N application	kg	440	100
Product		silage	silage
Landscape area	%	0	5
Slurry			
Total production	m^3	102	63
Grass, injection	m^3	34	7
Grass, surface application	m^3	68	56
Others			
Stocking rate	cows	3.29	2.47
Milk production	kg	26.300	19.770
Labour input	h	122	92
Concentrates	kg	13.130	10.260
N fertiliser	kg	240	0
N surplus	kg	395	170
P surplus	kg	29	31
Labour income per t milk	Dfl t^{-1}	200	174

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Appendix I:

Input requirements of NTEGRATE

I.1. General

	Unit
- general information of the location of the field :	
latitude	degrees

I.2. Weather

- for each day standard meteorological data :	
daily total of solar radiation (shortwave)	kJ m^{-2} d^{-1}
daily minimum temperature	°C
daily maximum temperature	°C
early morning vapour pressure	kPa
daily average wind speed	m s^{-1}
daily precipitation	mm d^{-1}

Precipitation should be measured at the field, whereas the other data can be obtained from the nearby weather station(s).

I.3. Management

- for each cut or grazing period :	
target grass yield	kg DM ha^{-1}
maximum number of growing days until harvesting	d
duration of grazing periods	d
number of days between cutting and removing cut grass	d
amount of grass lost at harvesting	kg DM ha^{-1}
amount of grass left after harvesting (stubble)	kg DM ha^{-1}
occurrence of a cleaning cut in case of grazing?	yes or no
removal of cut grass of a cleaning cut?	yes or no
amount and timing of nitrogen fertilisation	kg N ha^{-1}

By means of the *max. no. of growing days* a known harvesting calendar can be used as input ; otherwise the *target grass yields* are used to determine the dates at which harvesting is simulated.

- animal data :

number of animals per grazing period	animal ha^{-1}
milk/meat production	kg $(animal)^{-1}$ yr^{-1}
number of hours spent in the field	h d^{-1}
dry matter intake of grass and supplements	kg DM $(animal)^{-1}$ d^{-1}
nitrogen concentration of milk/meat and supplements	g N $(g\ DM)^{-1}$
carbon concentration of milk/meat and supplements	g C $(g\ DM)^{-1}$
ratio of digestible to indigestible nitrogen for grass and supplements	-
carbon to nitrogen ratio in faeces	g C $(g\ N)^{-1}$
carbon to nitrogen ratio in urine	g C $(g\ N)^{-1}$
area of an urine patch	m^{-2}
urine volume per urination	kg
total urine volume as a function of excreted urinary N	kg $(animal)^{-1}$ d^{-1}

I.4. Grass growth

- light interception and production parameters :

scattering coefficient of leaves for PAR	-
extinction coefficient for PAR	-
light use efficiency as function of temperature, transpiration ratio and leaf nitrogen concentration	g DM (MJ $PAR)^{-1}$

PAR is the photosynthetically active radiation (kJ m^{-2} d^{-1}) and equals approximately half of the total daily shortwave radiation. *Transpiration ratio* equals the quotient between actual and potential transpiration of the grass crop.

- dry matter partitioning :

dry matter partitioning coefficients for leaves (laminae), sheaths, stems and roots under potential production conditions	-
increase in root dry matter partitioning coefficient as function of the transpiration ratio and the nitrogen concentration in new leaves	-
maximum carbohydrate reserve level in stem/sheath	-
maximum relative remobilisation rate of carbohydrate reserves	d^{-1}
carbon fraction in plant biomass	g C $(g\ DM)^{-1}$

- leaf and root dynamics :

specific leaf area as function of days after harvesting	m^2 $(g\ DM)^{-1}$
relative leaf decrease rate as function of leaf area index	d^{-1}
increase in leaf decrease rate as function of transpiration ratio and leaf nitrogen concentration	d^{-1}
rooting depth as function of root biomass or soil conditions	m
relative root decrease rate as function of air temperature	d^{-1}

- nitrogen :

maximum nitrogen concentrations of leaves, stems/sheaths and roots as function of leaf area index	g N (g DM)$^{-1}$
minimum nitrogen concentrations of leaves, stems/sheaths and roots	g N (g DM)$^{-1}$
maximum nitrogen relocation fractions before abscission of plant parts	-
threshold parameter to calculate the effect of nitrogen demand on actual nitrogen relocation fractions	g N m^{-2} d^{-1}
time coefficient for calculating a delay in the uptake of nitrogen as function of the nitrogen demand	d

Nitrogen demand is defined as the difference between maximum and actual nitrogen content in the plant divided by the time step of integration.

- harvesting :

amount of harvestable shoot biomass as function total shoot biomass	g DM m^{-2}
stubble leaf area index at harvesting as function of harvested biomass	m^{2} m^{-2}
leaf fraction of the grass biomass intake at grazing	-
stubble leaf nitrogen concentration at harvesting as function of the leaf area index before and after harvesting	g N (g DM)$^{-1}$

- initial values

leaf, stem/sheath and root biomass	g DM m^{-2}
amount of carbohydrate reserves in the stem/sheath	g CH_2O m^{-2}
amount of nitrogen in leaves, stems/sheaths and roots	g N m^{-2}
leaf area index	m^{2} leaf (m ground)$^{-2}$

I.5. Soil water

The soil profile is described by a number of *soil layers*, which are defined by their soil moisture retention and hydraulic conductivity curves and other chemical/physical characteristics (see also sections on soil temperature and soil nitrogen). Each *soil layer* may contain a number of *soil compartments* with equal soil chemical/physical characteristics. A soil compartment is the smallest discretisation unit of the soil profile with a thickness varying from 1 to 5 cm at the top of the profile to 20 cm at the bottom.

- for each soil layer :

depth of lower boundary	dm
relation between pressure head (cm) and hydraulic conductivity	cm d^{-1}
relation between soil moisture content (cm^{3} cm^{-3}) and pressure head (= soil moisture retention or pF curve)	cm
occurrence of hysteresis in the retention curve	yes or no
trigger value for a reversal in the hysteresis scanning curves	cm
occurrence of preferential paths for water transport (i.e. cracks)	yes or no
parameters to calculate preferential water transport	

- parameters related to the top boundary condition :

crop factors to relate ET of the reference crop to ET of grass	-
extinction coefficient for shortwave radiation	-
reduction of transpiration as function of pressure head and atmospheric demand	-
relation between leaf area index and interception of precipitation	cm d^{-1}
surface storage capacity (ponding)	cm

ET is evapotranspiration of the soil-vegetation system (mm d^{-1})

- parameters related to the bottom boundary condition :
  groundwater level (cm) or flux density (cm d^{-1}) through the bottom boundary or pressure head (cm) in bottom compartment as function of day of the year

- definition of surface water system for drainage/infiltration :

distance between drainage media	m
depth of drainage media	cm
wet perimeter of drainage media	cm
base of the aquifer	m
open water level as function of day of the year (if drainage medium = ditch)	cm
horizontal saturated hydraulic conductivity	cm d^{-1}
shape factor of groundwater level	-

- initial values :

groundwater level	cm

I.6. Soil temperature

- for each soil layer :

relation between soil moisture content and thermal capacity	J m^{-3} °C^{-1}
relation between soil moisture content and thermal conductivity	W m^{-1} °C^{-1}

I.7. Soil nitrogen

- parameters for turnover processes :

fraction of fresh organic matter that dissolves at decomposition	-
assimilation efficiency of the microbes	-
fraction heterotrophic biomass of total microbial biomass	-
average relative decomposition rate of dissolved organic matter	yr^{-1}
average relative decomposition rate of humus	yr^{-1}
average relative nitrification and denitrification rate	yr^{-1}
nitrogen fraction in humus	kg N (kg humus)$^{-1}$
reduction on average turnover rates as function of soil temperature, pH, moisture content and O_2	-

In the soil a number of fresh organic matter classes are distinguished. Each *OM class* is characterised by a nitrogen concentration and a relative decomposition rate.

nitrogen concentration of each OM class	kg N (kg DM)$^{-1}$
average relative decomposition rate of each OM class	yr^{-1}

- material characterisation :

A number of materials can be added to the soil, e.g. chemical and organic fertiliser, urine, faeces, plant residues, etc. The organic part of each material is distributed among the *OM classes* and further divided into fresh organic matter and dissolved organic matter.

fraction of organic matter in each material	-
fraction of mineral NH_4-N and NO_3-N in each material	-
fraction of the organic part of each material which corresponds with a OM class	-
fraction of the organic part of each material which goes into solution	-

- parameters related to deposition and other inputs to the soil profile :

atmospheric dry deposition of NH_4-N and NO_3-N	kg N ha^{-1} yr^{-1}
concentration of NH_4-N and NO_3-N in the precipitation	kg N m^{-3}
concentration of NH_4-N and NO_3-N in the sprinkling water	kg N m^{-3}
concentration of NH_4-N and NO_3-N in the infiltrating drain water	kg N m^{-3}
concentration of NH_4-N and NO_3-N in the seepage water	kg N m^{-3}
concentration of dissolved organic matter in the infiltr. drain water	kg m^{-3}
concentration of dissolved organic nitrogen in the infiltr. drain water	kg N m^{-3}
concentration of dissolved organic matter in the seepage water	kg m^{-3}
concentration of dissolved organic nitrogen in the seepage water	kg N m^{-3}

- parameters related to nitrogen uptake :

diffusion coefficients for nitrate and ammonium uptake	d^{-1}
selectivity factors for nitrate and ammonium uptake by mass flow	-

- chemical/physical characteristics <u>for each soil layer</u> :

dry bulk density	kg m^{-3}
pH-KCl	-
two parameters to calculate the diffusion of oxygen in the airfilled part of the soil	-
adsorption constant for linear sorption of NH_4-N	m^3 kg^{-1}

- initial values <u>for each soil compartment</u>:

concentration of NH_4-N and NO_3-N in the soil solution	kg N m^{-3}
concentration of dissolved organic matter in the soil solution	kg m^{-3}
concentration of dissolved organic nitrogen in the soil solution	kg N m^{-3}
amount of humus	kg m^{-2}
amount of fresh organic matter of each OM class	kg m^{-2}

Appendix II : Output of NTEGRATE

II.1. Grass growth

	Frequency
- terms of the grass balance	
total gross dry matter production	continuously
total gross nitrogen uptake by the plant roots	continuously
amount of dry matter, carbon and nitrogen removed by harvesting	continuously
amount of dry matter, carbon and nitrogen lost at harvesting	continuously
amount of dry matter, carbon and nitrogen incorporated into the soil due senescence of leaves, stems and roots	continuously
- state variables	
amount of dry matter, carbon and nitrogen in live and dead leaves, stems, sheaths and roots	(two-)weekly
green and dead leaf area index	(two-)weekly
rooting depth	(two-)weekly

II.2. Soil water

- terms of the water balance :	
actual evaporation / transpiration	continuously
actual infiltration through the soil surface	continuously
amount of drainage or subsurface infiltration water	continuously
amount of percolation or seepage through the bottom of the soil profile	continuously
- state variables	
soil moisture contents and pressure heads distributed over depth and time	weekly
groundwater level	weekly

NTEGRATE calculates the changes in the state variables of each soil compartment in the soil profile. For Dutch soils a profile with a standard depth of 4 m has been chosen and 38 soil compartments are used for simulating the soil water balance.

II.3. Soil temperature

- state variables

soil temperature distributed over depth and time	weekly

II.4. Soil nitrogen

- terms of the nitrogen balance :

amount of NH_3-volatilisation	continuously
amount of N-loss through denitrification	continuously
discharge of nitrogen (NH_4, NO_3 and dissolved organic N) to surface water and deep soil layers	continuously
supply of nitrogen (NH_4, NO_3 and dissolved organic N) from surface water and deep soil layers	continuously
supply of nitrogen and organic matter in plant residues (leaves, stems and roots)	continuously
net mineralisation of nitrogen	continuously

Other terms of the nitrogen balance (fertilisation and deposition) are described as input requirement.

- state variables :

mineral nitrogen (NH_4, NO_3) in the soil solution and adsorbed NH_4 distributed over depth and time	weekly
nitrogen in fresh organic matter, dissolved organic matter and stabilised organic matter (humus) distributed over depth and time	weekly
fresh organic matter, dissolved organic matter and stabilised organic matter (humus) distributed over depth and time	weekly
pH (H_2O) distributed over depth and time	weekly

For simulating the soil nitrogen balance 32 soil compartments are used.

Appendix III:
Input requirements for GRASMOD

III.1. Default values of parameters used in GRASMOD

```
* For more detailed information on the parameters is referred to
* CABO-report 158, 1992 (G.W.J. van de Ven)

The name of the farm listed in the output file of GRASMOD
FARM = 'DEFAULT'

* number of N application levels, optional
IN = 8

* N fertiliser application [kg N/ha/yr]
NFERTD =
  100.,
  150.,
  200.,
  250.,
  300.,
  350.,
  400.,
  450.

* Number of herbage supply levels (explained in text)
IC = 3

*  herbage supply level (explained in text)
HSD =
1.0,
0.9,
0.8

* number of milk production levels
IM = 4

* annual milk production level per cow [kg/cow/yr]
MILKD =
   0.,
5000.,
6500.,
8000.
```

```
* the number of grassland utilisation methods
IG = 8

* parameters depending on the grassland utilisation method G:
* 1: zero grazing dairy cows, no supply maize silage
* 2: zero grazing dairy cows, supply maize silage
* 3: zero grazing calves
* 4: zero grazing yearlings
* 5: day and night grazing dairy cows (no supply of maize silage)
* 6: day grazing only dairy cows (supply of maize silage)
* 7: day and night grazing calves
* 8: day and night grazing yearlings

* AREAF  : area of a faeces patch [ha ha-1]
* AREAU  : area of a urine patch [ha ha-1]
* COI    : daily concentrate intake by calves [kg d-1]
* CONCEP : amount of N incorporated in embryo in a pregnant yearling [kg
           N]
* D      : duration of the grazing season [d]
* ENRS   : energy requirements as determined by grazing system only
           [MJ cow-1 d-1]
* ENRYS  : energy requirements [MJ animal-1 yr-1]
* FLDMG  : feeding losses of grass consumed fresh as a fraction of the
           amount produced [-]
* FSYS   : correction factor for maximum roughage intake depending
           ongrazing system [-]
* GF     : part of the day cows are grazing fresh as a fraction of the
           amount produced [-]
* GHLDMG : grazing and harvest losses of grass [-]
* GROWTH : growth of young stock in grazing season [kg animal-1 d-1]
* MAIDC  : daily intake of maize silage [kg cow-1 d-1]
* MF     : part of the day animals are not in milking stable [-]
* AK/AP  : parameters calculation K and P fertilisation, depending on
*          grassland utilisation method [kg K ha-1, kg P ha-1]
```

AREAF	AREAU	COI	CONCEP	D	ENRS	ENRYS	FLDMG	FSYS	GF
.000008	.000068	.0	.0	184.	1.59	0.	.05	0.87	.0
.000008	.000068	.0	.0	184.	1.59	0.	.05	0.87	
.000004	.000035	.85	.0	129.	0.	3371.	.05	.00	.0
.000006	.000050	.0	.323	184.	0.	8185.	.05	.00	.0
.000008	.000068	.0	.0	184.	7.32	0.	.0	1.00	1.
.000008	.000068	.0	.0	184.	6.42	0.	.0	0.90	0.5
.000004	.000035	.85	.0	129.	0.	3756.	.0	.00	1.0
.000006	.000050	.0	.323	184.	0.	9276.	.0	.00	1.0

GHLDMG	GROWTH	MAIDC	MF	AK	AP
.07	.0	0.	0.8333	0.	0.
.07	.0	4.5	0.8333	0.	0.
.07	.850	0.	1.0	0.	0.
.07	.625	0.	1.0	0.	0.
.20	.0	0.	0.8333	60.	0.
.14	.0	4.5	0.8333	150.	30.
.18	.850	0.	1.0	60.	0.
.18	.625	0.	1.0	60.	0.

* grass yield [kg DM ha-1 yr-1] as determined by N uptake [kg N ha^{-1} yr-1] for various cut weights, 1.7, 2.3, 3.0 and 4.0 ton dm ha-1, respectively. A non-orthogonal hyperbola is fit through experimental data. This relation is characterised by 3 parameters, A, B and C.

```
A17 =  22.25;    A23 =  20.253;    A30 =  18.93;    A40 =  18.194
B17 = 305.8;     B23 = 310.1;      B30 = 303.2;     B40 = 298.6
C17 =  12.9;     C23 =  14.5;      C30 =  15.1;     C40 =  15.5
```

* N uptake depending on N availability from fertiliser mineralisation, deposition and urine [kg N ha-1 yr-1]. A non-orthogonal hyperbola is fit through experimental data. This relation is characterised by 3 parameters, A, B, and C.

```
ANUP =   1.1793
BNUP = 725.5
CNUP = 605.
```

* nitrate leaching from fertiliser, standard (IFLMAX, IFL)

```
*          N rate      N leaching (kg N ha-1 yr-1)
TNO3F =     0.,           0.,
           50.,           1.,
          100.,           3.,
          150.,           6.,
          200.,           9.,
          250.,          12.,
          300.,          16.,
          350.,          25.,
          400.,          39.,
          450.,          63.,
          500.,          91.,
          550.,         121.,
          600.,         153.,
         1000.,         433.,
         5000.,         433.
```

```
* P content in grass as determined by N content (both in kg kg-1),
(IPNMAX, * IPN)
*            N           P
CPG    = 0.008,      0.0018,
         0.016,      0.0028,
         0.024,      0.0036,
         0.032,      0.0042,
         0.040,      0.0048,
         0.048,      0.0051

* number of grass products distinguished:
* 1: Hay, cut at 4 t DM
* 2: Silage cut at 4 t DM
* 3: Silage cut at 3 t DM
* 4: artificially dried grass cut at 3 t DM
* 5: fresh grass cut at 2.3 t DM
* 6: fresh grass grazed at 1.7 t DM
IE = 6

* Parameters used to calculate the feeding value of grass and harvest
* losses of cut grass as determined by harvesting stage (IEMAX,IE)
* CASHA/B : regression parameters to calculate crude ash from N content
* CF      : crude fibre content grass [g kg-]
* CFAT    : crude fat content grass [g kg-1]
* D       : average number of growing days after 1 april [d]
* FP      : fermentation products grass [g kg-1]
* FDCASH  : fraction digestible crude ash [fraction]
* HLDMC   : harvest losses conserved grass [fraction]

CASHA  CASHB     CF  CFAT   DAY     FP  FDCASH    HLDMC
 1.15    78.   275.   35.    91.    0.     50.      .35
 1.15    78.   260.   40.    91.   47.     50.      .15
 1.15    78.   240.   40.    76.   47.     50.      .15
 1.18    95.   240.   30.    76.    0.     35.      .05
 0.97    63.   215.   40.   106.    0.     50.      .0
 1.14    59.   205.   40.   106.    0.     50.      .0

* protein digestibility [fraction] of maize as determined by N
concentration [kg kg-1] (IMAMAX,IMA)
*       N content  digestiblity
PDCMT =  .0100,      0.36,
         .0105,      0.39,
         .0120,      0.47,
         .0125,      0.49,
         .0130,      0.50,
         .0140,      0.54,
         .0145,      0.55
```

```
* fraction of N in urine that volatilises and the fraction N not
accounted * for in urine patches as determined by N application rate
* [kg N ha-1  yr-1](IBUMAX, IBU)
*         N appl.     NH3 loss
           rate
TFNH3U=       0.,       0.02,
            550.,       0.13,
            600.,       0.13

*         N appl.  N not accounted
           rate    for in urine patches
TFNBLU=    0.,       0.38,
         550.,       0.27,
         600.,       0.27

* K uptake from fertiliser, [kg K ha-1 yr-1] (IKMAX, IK)
*        K rate   K uptake
TKUPF =     0.,        0.,
          400.,      280.,
         3000.,      930.,
         5000.,      930.
* Number of concentrate types available
IT = 4

* data relating to concentrate type C:
* CN    : N content [kg kg-1]
* CP    : P content [kg kg-1]
* DVEC  : DVE content [g kg-1]
* FDCP  : fraction digestible crude protein [-]
* OEBC  : rumen degradable protein balance [g kg-1]

   CN       CP  DVEC     FDCP   OEBC
.0147   .0032    65.     0.65   -21.
.0230   .0050   100.     0.75   -11.
.0230   .0055   100.     0.65   -20.
.0220   .0055    65.     0.70    20.

* number of periods distinguished in summer. The ration of dairy cows is
calculated in dependence of milk production. To be able to calculate a
realistic ration, the lactation period is divided in four periods. The
fifth period in the year are the months the cows are not milked. 2 of
these 5 periods are in summer.
IP = 2
```

```
* data relating to summer periods 1 and 2
* DVERC : daily DVE requirement for conception products [g cow-1 d-1]
* ENRC  : daily energy requirement for conception products [MJ cow-1 d-1]
* MILKPR: fraction of the annual milk production produced in period P [-]
* PERIOD: number of days in period P
* R     : reduction factor herbage intake depending on lactation
         stage [-]

DVERC    ENRC   MILKPR PERIOD       R
   0.     0.25    0.269     77.    1.00
  13.     1.35    0.266    107.    0.95

* replacement rate of forage by concentrates [kg forage kg-1
concentrates]
RC     =   0.3, 0.5, 0.7

* reduction factor energy intake in first period in summer, compensated
in * following periods [-]
*       milk   corr. factor
PRFCT = 4500.,    0.975,
        8000.,    0.925,
       10000.,    0.900,
       15000.,    0.850

* single values
BK     = 140.         ! BK, CK, DK parameters for calculation of K
                        fertiliser
CK     = 70.          ! application in dependence of grassland
                        utilisation
DK     = 100.         ! method according to the recommendations [kg K]
BP     = 45.          ! BP, CP idem P [kg P]
CP     = 20.          !
C2     = 2300.        ! cut weight at zero grazing [kg DM ha-1]
C3     = 3000.        ! cut weight at cutting for silage [kg DM ha-1]
CKMEAT = 0.0020       ! K content meat [kg kg-1]
CKMILK = 0.0016       ! K content milk [kg kg-1]
CNMEAT = 0.025        ! N content meat [kg kg-1]
CNMILK = 0.0053       ! N content milk [kg kg-1]
CKM    = 0.017        ! K content concentrates [kg kg-1]
CKCON  = 0.015        ! K content maize silage [kg kg-1]
CPMAI  = 0.0022       ! P content maize silage [kg kg-1]
CPMILK = 0.0009       ! P content milk [kg kg-1]
CPMEAT = 0.0080       ! P content meat [kg kg-]
DM     = 450.         ! DM content pre-wilted silage [g kg-1]
DVEMAI = 47.          ! DVE content maize silage [g kg-1]
DVERM  = 121.         ! DVE requirement for maintenance [g cow-1 d-1]
ENRG   = 1.28         ! energy requirements for growth [MJ cow-1 d-1]
FLDMC  = 0.05         ! feeding losses of conserved herbage [-]
FKUR   = 0.9          ! fraction of K excreted in urine [-]
FNH3   = 6.           ! NH3 fraction in pre-wilted silage
```

```
FNH3F  = 0.13       ! fraction of N in faeces that volatilises [-]
FNH3G  = 0.03       ! fraction N in dead herbage that volatilises [-]
FUPSEA = 0.65       ! part of the growing season that N is taken up
                      by the crop [-]
GE     = 18410.     ! gross energy content of herbage [kJ kg-1]
KDP    = 9.         ! K deposition [kg ha-1 yr-1]
KNA    = 47.75      ! regression parameter for calculating the K
                      content in grass from the N content [kg K/kg N]
KNB    = 1.582      ! idem [kg K kg-1 DM]
KNC    = 1.4        ! desired K/N ratio in grass
KURINE = 0.9        ! fraction of the excreted K in urine [-]
KRECI  = 0.70       ! K recovery from fertiliser [kg K taken up/kg K
                      applied]
KUPSL  = 175.       ! K uptake from soil reserves [kg ha-1 yr-1]
LWCOW  = 600.       ! liveweight cows [kg cow-1]
MAXDP  = 0.70       ! maximum fraction of K and N deposited annually
                      available to plants in the growing season [-]
MAXNOM = 0.95       ! maximum fraction of N mineralised available to
                      plants [-]
MAXNUS = 0.6        ! maximum fraction of N in urine available to
                      plants [-]
MEATPR = 60.        ! annual meat production per cow (incl. calf)
                      [kg cow-1]
MJCON  = 7.21       ! energy value of concentrates [MJ kg-1 DM]
MJMAIS = 6.23       ! energy value of maize silage [MJ kg-1 DM]
NDP    = 45.        ! N deposition [kg N ha-1 yr-1]
NH3FRC = 0.09725    ! N volatilised from stables [-]
NORM   = 1.00       ! deviation from the feeding standard (if farmers
                      indicate they feed above or below the norm) [-]
NRECI  = 0.85       ! initial N recovery, i.e. Ntaken up from
                      mineralised N, deposited N and low
                      N application levels[-]
NO3OM  = 13.        ! nitrate loss from unfertilised fields
                      [kg N ha-1 yr-1]
NOM    = 153.       ! net N mineralisation in the soil
                      [kg N ha-1 yr-1]]
NRFE   = 12.        ! number of faeces excretions per cow per day
NRUE   = 12.        ! number of urine excretions per cow per day
OEBMAI = -16.       ! OEB value of maize silage [g kg-1]
PDEP   = 0.9        ! P deposition [kg P ha-1 yr-1]
SUMMLK = 0.535      ! fraction of the annual milk yield produced in
                      summer [-]
SWG    = 0.55       ! structure value of grass [-]
SWM    = 0.65       ! structure value of maize silage [-]
```

III.2. Parameters required to calculate the nutritive value of herbage

- The energy value of herbage [MJ kg^{-1} DM] depends on:
  * digestible organic matter content [g kg^{-1}]
  * digestible crude protein content [g kg^{-1}]
  * gross energy content [MJ kg^{-1} DM]
- The DVE (protein digested in the small intestine, g kg^{-1}) and the OEB (degraded protein balance, g kg^{-1}] depend on:
  * digestible crude protein content [g kg^{-1}]
  * digestible organic matter content [g kg^{-1}]
  * crude fat content [g kg^{-1}]
  * undegraded starch [g kg^{-1}]
  * fermented organic matter [g kg^{-1}]
  * end products of fermentation in ensiled feeds (fraction NH3)[g kg^{-1}]

III.3. Parameters required to calculate the ration of the animals

- total energy requirements [MJ cow^{-1} d^{-1}] are composed of:
  * requirement for maintenance, depending on liveweight;
  * requirements for milk production, depending on milk production level;
  * requirement for growth. During the first two years a liveweight increases from 520 to 600 kg;
  * requirements depending on the grazing system. Day and night grazing requires a higher energy input than zero grazing;
  * requirements for growth of conception products;
  * additional requirements due to an inevitable energy shortage in the first period of milk production. This is a fraction of the total energy requirement in that period.
- Maximum dry matter intake from roughage depends on energy content of the roughage, milk production level and grazing system [kg DM cow^{-1} d^{-1}].
- herbage can be replaced by maize silage, depending on the energy content of both feeds and maximum DM intake [kg herbage kg^{-1} maize silage].
- Concentrates replace roughage depending on the amount that has to be supplied to meet the energy requirements [kg roughage/kg concentrates].

Appendix IV:
List of indices used in the IMGLP model

The indices refer to the characteristics of the production techniques (first column Figure 3). Note that the index G in GRASMOD is split into B and Y in the IMGLP model. For the indices M, N and S the standard values are given, but these can easily be changed. The values for N are defined in the file DEFAULT.INP for GRASMOD and the values are transported automatically to the input for the IMGLP model. For the others this still has to be done by hand at this moment.

Indices:

A: method to apply slurry	1.	deep injection
	2.	injection with open slits/ploughing after application
	3.	surface spreading
B: grassland utilisation method	1.	zero grazing, no supply of maize silage
	2.	zero grazing, supply of maize silage
	3.	day-and-night grazing
	4.	day grazing, supply of maize silage
C: herbage supply	1.	maximum herbage intake
	2.	90% of the maximum herbage intake, extra concentrates
	3.	80% of maximum herbage intake, extra concentrates
F: conserved grass, consumed in winter	1.	hay, harvested at 4000 kg dm ha^{-1}
	2.	grass silage, harvested at 4000 kg dm ha^{-1}
	3.	grass silage, harvested at 3000 kg dm ha^{-1}
	4.	artificially dried grass, harvested at 3000 kg dm ha^{-1}
G: number of crop types	1.	grass consumed fresh in summer
	2.	conserved grass, consumed in winter
	3.	maize
	4.	fodder beet
L: treatment of fodder beet leaves	1.	leaves are left in the field
	2.	leaves are harvested
M: milk production levels	1.	no milk (young stock)
	2.	5000 kg per cow per year
	3.	6500 kg per cow per year
	4.	8000 kg per cow per year

N: fertiliser application rates

	grass kg N ha^{-1} yr^{-1}	maize + fodder beet % inorganic N fertiliser
N1	100	100
N2	150	75
N3	200	50
N4	250	0
N5	300	-
N6	350	-
N7	400	-
N8	450	-

P: periods in a year
1. summer
2. winter

Q: type of maize products
1. silage maize
2. ground ear silage

R: method of fertilisation
1. broadcasting both inorganic fertiliser and slurry
2. banded placement of inorganic fertiliser
3. banded placement of slurry
4. banded placement of both inorganic fertiliser and slurry

S: production level and product quality

S	maize		fodder beet	
	dm yield t ha^{-1} yr^{-1}	N content g kg^{-1}	dm yield t ha^{-1} yr^{-1}	N uptake kg ha^{-1}
1	14,3	13	22	265
2	13,7	12	-	-
3	12,7	11	-	-

T: concentrate type

		g N kg^{-1}	g P kg^{-1}
1.	protein poor	14,7	3,2
2.	standard	23	5,0
3.	moderately protein poor	20	5,0
4.	protein rich	32	5,5
5.	very protein rich	64	12,2
6.	P poor	23	3,5

W: catch crop under maize in winter time
1. no catch crop
2. growing a catch crop

Y: type of cattle	1.	dairy cows (> 2 years)
	2.	calves (0-1 year old)
	3.	yearlings (1-2 year old)
Z: type of stable and storage	1.	current type
	2.	storage covered, stable adapted to low ammonia emissions

Appendix V: Input requirements of the IMGLP-model

The meaning and standard values of the indices are given in Appendix IV

V.1. Data supplied to the IMGLP-model by GRASMOD

N and P flows		
BLON(Y,B,N,C,M)	organic N balance of grass production techniques	[kg N.ha-1]
BLONF(F,N)	organic N balance of forage production techniques	[kg N.ha-1]
BLPF(F,N)	P balance of forage production techniques	[kg P ha-1]
BLPG(Y,B,N,C,M)	P balance of grass production techniques	[kg P ha-1]
N2OU(Y,B,N,C,M)	balance loss from urine patches (chemo-denitrification)	[kg N ha-1]
NH3F(F,N)	NH3 loss from forage production techniques	[kg N.ha-1]
NH3G(Y,B,N,C,M)	NH3 loss from grass production techniques	[kg N.ha-1]
NH3ANL(Y,B,N,C,M)	NH3 loss from stable and storage in summer	[kg N head-1]
NLOSSF(F,N)	N loss from rooted zone for forage production techniques	[kg N.ha-1]
NLOSSG(Y,B,N,C,M)	N loss from rooted zone for grass production techniques	[kg N.ha-1]
PNW(Y,M)	N in milk and meat in winter time	[kg N head-1]
PPW(Y,M)	P in milk and meat in winter time	[kg P head-1]
SLN(Y,B,N,C,M)	N collected in slurry in summer	[kg N.ha-1]
SLP(Y,B,N,C,M)	P collected in slurry in summer	[kg P.ha-1]
Nutrient requirement		
FKI(F,N)	fertiliser K requirement of forage production techniques	[kg K ha-1]
FNI(F,N)	fertiliser N requirement of forage production techniques	[kg N.ha-1]
GKI(Y,B,N,C,M)	fertiliser K requirement of grass production techniques	[kg K.ha-1]
GNI(Y,B,N,C,M)	fertiliser N requirement of grass production techniques	[kg N.ha-1]
feeding value		
FCN(F,N)	N content of cut grass	[kg N.kg-1]
FCP(F,N)	P content of forage	[kg P.kg ds]
FDVE(F,N)	DVE content of cut grass	[kg dve.kg-1]
FES(F,N)	energy content of cut grass	[MJ.kg-1]
FOEB(F,N)	OEB content of cut grass	[kg.kg-1 DM]
FPDC(F,N)	fraction protein digestibility of conserved grass	[-]
Animals		
DMMX(Y,M)	maximum dry matter intake from roughage in winter	[kg cow-1]
DVEI(Y,M)	DVE requirement animals in the winter period	[kg dve.ha-1]
EI(Y,M)	energy requirement cattle in winter time	[MJ.ha-1]
PREQM(Y,M)	P requirements in winter	[kg P head-1]
RC(Y,M)	replacement rate of roughage by concentrates	[kg kg-1]

miscellaneous

CIS(Y,B,N,C,M,T)	required amount of concentrates in the summer period	[kg.ha-1]
FDM(F,N)	dry matter yield of forage production techniques	[kg.ha-1]
NRCUT(F,N)	number of cuts for product type F	[ha-1]
NRCUTS(Y,B,N,C,M)	number of grazing periods/cuts for grass used in summer	[ha-1]
SR(Y,B,N,C,M)	stocking rate	[head.ha-1]
ZDMI(B,N,C,M,Q)	required amount of maize products in summer	[kg.ha-1]

V.2. Data supplied by the TCG for maize and fodder beet

If no beet or maize is grown for each crop one parameter, initialising the type of production techniques considered, has to be set to 0.

yield and N content

YMAIS(S,Q)	maize yield of continuous maize cultivation for product type Q and N content S	[kg DM ha-1]
YMAISB(S,Q)	maize yield in maize/fodder beet rotation for product type Q and N content S	[kg DM ha-1]
YBEET(S)	fodder beet yield	[kg DM ha-1]
YLEAF(S,L)	beet leaves yield	[kg DM ha-1]
BBCN(S)	N content of fodder beets	[kg N kg-1]
BLCN(S)	N content of beet leaves	[kg N kg-1]
MCN(S,Q)	N content of maize products	[kg N kg-1 DM]

N and P flows

BLONB(S,N,A,R,L,W,Q)	organic N balance of fodder beet production techniques	[kg N.ha-1]
BLONM(S,N,A,R,W,Q)	organic N balance of maize production techniques	[kg N.ha-1]
BLPB(S,N,A,R,L,W,Q)	P balance of fodder beet rotation	[kg P ha-1]
BLPM(S,N,A,R,W,Q)	P balance of maize production techniques	[kg P ha-1]
NLOSSB(S,N,A,R,L,W,Q)	N loss from rooted zone for fodder beet production techniques	[kg N.ha-1]
NLOSSM(S,N,A,R,W,Q)	N loss from rooted zone for maize production techniques	[kg N.ha-1]

fertiliser requirement

BKI(S,N,A,R,L,W,Q)	fertiliser K requirements of fodder beet production techniques	[kg N.ha-1]
BNI(S,N,A,R,L,W,Q)	fertiliser N requirements of fodder beets production techniques	[kg N ha-1]
BPI(S,N,A,R,L,W,Q)	fertiliser P requirements of fodder beets production techniques	[kg P ha-1]
BSI(S,N,A,R,L,W,Q)	slurry N requirement of fodder beet production techniques	[kg N.ha-1]
MKI(S,N,A,R,W,Q)	fertiliser K requirement of maize production techniques	[kg ha-1]
MNI(S,N,A,R,W,Q)	fertiliser N requirement of maize production techniques	[kg ha-1]
MSI(S,N,A,R,W,Q)	slurry N requirement of maize production techniques	[kg ha-1]
MPI(S,N,A,R,W,Q	fertiliser P requirement of maize production techniques	[kg ha-1]

V.3. Additional data

Parameters describing the boundaries of the system:

RHO	total area available	[ha]
RHSGR	grassland area	[ha]
RHSMA	maize area	[ha]
RHSQ2	area harvested as ground ear silage	[ha]
RHSBT	fodder beet area	[ha]
RLS	area reserved for landscape purposes (wooded banks)	[ha]
RHIRR	maximum area irrigated	[ha]
RLB	labour availability	[h ha^{-1}]
LSCB(G)	additional area required for landscape development related to beet cultivation	[ha.ha^{-1}]
LSCF(G)	additional area required for landscape development related to the area used for grass conservation	[ha ha^{-1}]
LSCG(G)	additional area required for landscape development related to the area under grazing	[ha ha^{-1}]
LSCM(G)	additional area required for landscape development related to maize cultivation	[ha ha^{-1}]
RLA	minimum number of animals outside summer for landscape purposes	[head]
MILK(M)	milk production level per cow	[kg koe^{-1}]
RMI	lower bound on milk production	[kg ha^{-1}]
BNDMK	upper bound on milk production	[kg]
FRMA	fraction of maize/fodder beet rotation harvested as MKS	[-]
BNDSL(A,G)	bound on slurry application method A for crop type G	[kg N]
RNI	maximum nitrate leaching loss	[kg N ha^{-1}]
RAM	maximum ammonia volatilisation	[kg N ha^{-1}]
RDE	maximum denitrification loss	[kg N ha^{-1}]
RGL	minimum fraction of stables meeting green label norms	[-]
RNO	maximum N surplus	[kg N ha^{-1}]
RPO	maximum P surplus	[kg P ha^{-1}]
RIL	minimum net income	[fl ha^{-1}]
RIN	minimum labour income	[fl ha^{-1}]

purchases

RHSPR(E)	upper bound on purchase of roughage type E	[kg]
FRCP	fraction of concentrates purchased	[-]
RHSP(Y)	number purchased animals per animal type	[head head^{-1}]
RHCMX	upper bound on amount concentrates purchased	[kg]
RHCMN	lower bound on amount of concentrates purchased	[kg]
BNDPS	upper bound on purchase of slurry	[kg N]
RHSPS	lower bound on purchased slurry	[kg N]

sales

BNDSM(S,Q)	upper bound on sale of maize type Q with N content S	[kg]
BNDSF(F,N)	bound on sale of conserved herbage type F with N fertiliser level N	[kg]
BNDSS	upper bound on sale of slurry	[kg N]
RHSSS	lower bound on sale of slurry	[kg N]

<u>additional data for crop production techniques:</u>

MINC(Y)	minimum ratio of the grass cut and grazed (grazed *grassland has to be cut at least once a year, e.g. with 5 cuts a year* MINC is 0.20)	[ha ha^{-1}]
DEN	fraction of the nitrate loss from the rooted zone that denitrifies	[-]
GRSMIN	N available after breaking up grass to maize and fodder beet after 3 years grass	[kg N yr^{-1}]
LBB	conservation and feeding losses fodder beet	[kg kg^{-1}]
LBL	conservation and feeding losses beet leaves	[kg kg^{-1}]
LC	conservation and feeding losses concentrates	[kg kg^{-1}]
LF(F)	conservation and feeding losses conserved grass type F	[kg kg^{-1}]
LM(Q)	conservation and feeding losses maize product type Q	[kg kg^{-1}]
LR	conservation and feeding losses purchased roughages	[kg kg^{-1}]
SILF(F)	*criteria for ensiling forage or not*	[-]
SILM(Q)	criteria for ensiling maize or not	[-]
SLMAX	maximum amount of slurry to be applied, based on potassium	[kg N.ha^{-1}]

<u>Animal production techniques</u>

BTM(Y)	maximum amount of fodder beet in winter for cows (Y=1)	[kg cow^{-1} d^{-1}]
RYSTC(Y)	ratio number of cows/number of young animals (fixed)	[head.$head^{-1}$]
DMCON	concentrates for calves first period	[kg $calf^{-1}$]
DMGS	grass silage for calves first period	[kg $calf^{-1}$]
DMH	hay for calves first period	[kg $calf^{-1}$]
ST	part of the diet that consists of structural material	[-]

<u>Parameters describing N and P flows</u>

RHSNS	amount of N sold with fodder	[kg N ha^{-1}]
AVS(Z)	factor for NH3 volatilisation from stable+storage type Z in summer	[-]
AVW(Z)	fraction of N in slurry volatilised from stable + storage type Z in winter	[kg N kg N]
GLN	green label norm from stable and storage	[kg N cow^{-1}]
KNR	K/N-ratio of slurry	[kg K kg^{-1} N]
LSCACC	nitrogen accumulation in landscape elements	[kg N ha^{-1}]
NLOSSL	nitrate loss from not cultivated land (landscape, nature)	[kg N ha^{-1}]
ONSL(A)	organic N in slurry added to the soil	[kg N kg^{-1} N]
NCMI	N content milk	[kg.kg^{-1}]
NC(Y)	N content per head of cattle type Y	[kg N $head^{-1}$]
NDEP	N deposition	[kg N ha^{-1}]
NH3A(A,G)	NH3 volatilisation associated with slurry application method A and crop type G	[kg N kg^{-1} N]
PC(Y)	P content of animal type Y	[kg P $head^{-1}$]
PCMI	P content milk	[kg P.kg $milk^{-1}$]
PDEP	P deposition	[kg P ha^{-1}]
PNR	P/N ratio in slurry	[kg P kg^{-1} N]
RNS(A,G)	recovery N slurry	[kg N kg^{-1} N]

<u>Economic data</u>

prices

PNOV	levy on N surplus	[fl kg^{-1}]
PPOV	levy on P surplus	[fl kg^{-1}]
RNHEF	levy free N surplus	[kg N ha^{-1}]
RPHEF	levy free P surplus	[kg Pha^{-1}]
PMILK	price milk	[fl.kg^{-1}]
PNFER	price N fertiliser	[fl.kg^{-1}]
PPFER	price P fertiliser	[fl kg^{-1}]
SALE(Y)	price for sale of animals per animal type	[fl head^{-1}]
PB	price sale fodder beet	[fl kg^{-1}]
PF(F)	price sale forage per product type F	[fl kg^{-1}]
PCONC(T)	price concentrates type C	[fl.kg^{-1}]
PADG(F)	costs of artificially drying grass	[fl kg^{-1} DM]
PAN(Y)	price animals produced surplus	[fl.head^{-1}]
PANP(Y)	price purchased animals	[fl.head^{-1}]
PKFER	price of K fertiliser	[fl kg^{-1}]
PLAB	costs of labour	[fl h^{-1}]
PPSL	costs of purchased slurry	[fl kg^{-1} N]
PSSL	price of slurry sold	[fl kg^{-1} N]
VCSTR(Y,B)	price of straw and sawdust for animals	[fl head^{-1}]

variable costs

VCB	variable costs beet cultivation	[fl ha^{-1}]
VCGF	variable costs grass cultivation	[fl ha^{-1}]
VCM(Q,W)	variable costs maize cultivation depending on crop type Q and with/without a catch crop	[fl ha^{-1}]
VCSIL	variable costs storing silage	[fl kg^{-1}]
VCY(Y)	variable costs of animals	[fl head^{-1}]

contract labour

CCLB	costs of contract labour fodderbeet	[fl ha^{-1}]
CCLF(F)	costs of contract labour forage	[fl ha^{-1}]
CCLG	costs of contract labour grass	[fl ha^{-1}]
CCLM(Q,W)	costs of contract labour maize	[fl ha^{-1}]
CCLSA(A,G)	costs of slurry application in contract labour	[gld.kg^{-1} N]

fixed costs

FIXF(F)	fixed costs for forage type F	[fl.ha^{-1}]]
FIXG(B)	fixed costs for grassland utilisation method B	[fl ha^{-1}]
FIXGY(Y,B)	fixed costs for manure storage depending on amount produced	[fl head^{-1}]
FIXL	fixed cost for rent of land	[fl ha^{-1}]
FIXY(Y)	fixed costs per animal type	[fl head^{-1}]
FIXZ(Y,Z)	fixed additional costs emission poor stable related to the number of dairy cows	[fl cow^{-1}]
FXFDBB	mechanisation costs for feeding fodder beet	[fl ton^{-1} DM]
FXFDBL	mechanisation costs for feeding beet leaves	[fl ton^{-1} DM]
FXFDC	mechanisation costs for feeding concentrates	[fl ton^{-1} DM]
FXFDF(F)	mechanisation costs for feeding conserved grass products	[fl ton^{-1} DM]
FXFDM	maize products	[fl ton^{-1} DM]
FXGRIR	costs for irrigation of grass 4x	[fl ha^{-1}yr^{-1}]
FXMAIR(S)	costs for irrigation of maize 1x	[fl ha^{-1}yr^{-1}]

labour requirements for:

LABT	cultivating, harvesting and conservation of fodder beet	[h ha^{-1}]
LACLS(Y,B)	cleaning stable and collecting animals in summer	[h $head^{-1}$]
LACLW(Y)	cleaning stable and collecting animals in summer	[h $head^{-1}$]
LAF(F)	growing grass for conservation with product type F	[h ha^{-1}]
LAFRT	fertiliser application	[h ha^{-1} $time^{-1}$]
LAG(B)	grass	[h cut^{-1} ha^{-1}]
LAGEN	additional labour required for general farm practises	[h ha^{-1}]
LAGF	grass fertiliser K, Mg, spraying	[h ha^{-1} yr^{-1}]
LAMLK(Y)	milking in summer/winter of dairy cows	[h $head^{-1}$]
LATBB	feeding fodder beet	[h ton^{-1} DM]
LATC	feeding concentrates	[h ton^{-1} DM]
LATF(F)	feeding conserved grass products type F	[h ton^{-1} DM]
LATBL	feeding fodder beet leaves	[h ton^{-1} DM]
LATM	feeding maize	[h ton-1 DM]
LATR(E)	feeding purchased roughages type E	[h ton^{-1} DM]
LAGRIR	irrigation grass	[h ha^{-1} yr-1]
LAMAIR(S)	irrigation maize	[h ha^{-1} yr^{-1}]

<u>Feeding value of various feeds</u>

RCN(E)	N content in purchased roughage type E	[kg N kg^{-1} DM]
RCP(E)	P content in purchased roughage type E	[kg P kg^{-1} DM]
RDVE(E)	DVE content in purchased roughage type E	[kg DVE kg^{-1} DM]
RES(E)	energy content in purchased roughage type E	[MJ kg^{-1}]
ROEB(E)	OEB content in purchased roughage type E	[kg OEB kg^{-1} DM]
RST(E)	structure value of purchased roughage type E	[-]
PROUG(E)	price purchased roughage type E	[fl kg^{-1}]
CCN(T)	N content of concentrate type C	[kg N.kg^{-1} DM]
CCP(T)	P content of concentrates type C	[kg P.kg^{-1} DM]
CDVE(T)	DVE content of purchased concentrates type C	[kg DVE kg^{-1} DM]
CES(T)	energy content of purchased concentrates type C	[MJ.kg^{-1} DM]
COEB(T)	OEB content of concentrates type C	[kg OEB kg^{-1}DM]
BBCP	P content in fodder beet	[kg P kg^{-1} DM]
BLCP	P content in beet leaves	[kg P kg^{-1} DM]
BBDVE	DVE content of fodder beet	[kg DVE.kg^{-1} DM]
BBES	energy content of fodder beet	[MJ.kg^{-1} DM]
BBOEB	OEB content of fodder beet	[kg OEB.kg^{-1} DM]
BLDVE	DVE content of beet leaves	[kgDVE.kg^{-1}]
BLES	energy content of beet leaves	[MJ.kg^{-1} DM]
BLOEB	OEB content of beet leaves	[kg OEB.kg^{-1} DM]
BLST	structural value of beet leaf	[-]
FST(F)	structural value of cut grass	[-]
MCP(Q)	P content of maize product Q	[kg P kg^{-1} DM]
MDVE(S,Q)	DVE content of maize product Q	[kg DVE kg^{-1} DM]
MES(Q)	energy content of maize product Q	[MJ kg^{-1} DM]
MKS(T)	MKS can substitute for concentrate type 1	[-]
MOEB(S,Q)	OEB content of maize products	[kg OEB kg^{-1} DM]
MST(Q)	structural material content maize products	[-]

Appendix VI:
Results of GRASMOD

INPUTS to the model

Farm/location	DEFAULT
- grassland management	day and night grazing (no supply of maize silage)
- N fertiliser rate (kg N ha^{-1})	250.
- cutting percentage (%)	100.
- milk production per cow (kg cow^{-1})	6500.
- type of concentrate	-
- herbage supply (-)	1.00

GRASSLAND	**total**	**fresh**	**silage**
dm gross (kg ha^{-1})	11667.	8667.	3000.
nett (kg ha^{-1})	9484.	6934.	2550.
N uptake (kg N ha^{-1})	379.	293.	86.
N content (%)		3.39	2.87
K uptake (kg K ha^{-1})	349.	270.	79.
K content (%)		3.11	2.63
desired K content (%)		3.20	2.95
nitrate loss (kg N ha^{-1})	45.		
volatilisation (kg N ha^{-1})	15.		
utilisation urine-N (%)	22.9		
utilisation u+f K (%)	31.2		
N fertiliser (kg N ha^{-1})	250.		
K fertiliser (kg K ha^{-1})	166.		
P fertiliser (kg P ha^{-1})	0.		
stocking rate (head ha^{-1})		2.44	

DAIRY COWS

	total	grass	maize	concentrates
milk production	8478.			
weight gain	74.			
intake per day (kg)	15.8	15.5	.0	.3
energy (MJ)	107.12	104.74	.00	2.37
nitrogen (kg)	.528	.523	.000	.005

N BALANCE GRASSLAND (kg ha^{-1} yr^{-1})

	total	uptake herbage	nitrate loss NO_3-N	volatil. NH_3-N	balance loss	organic N soil	immobil. (inorg.N)
mineralisation	153.	124.	13.				
	35.						
deposition	45.	27.					
fertiliser	250.	203.	12.				36.
urine	116.	27.	20.	8.	38.		23.
faeces	42.			5.		37.	
grazing/harvesting losses	72.			2.		70.	
total		379.	45.	15.	38.	107.	93.

N BALANCE SOIL (kg ha^{-1} yr^{-1})

INORGANIC N	in		out
mineralisation	153.	uptake herbage	379.
deposition	45.	nitrate loss	45.
fertiliser	250.	immobilisation	93.
urine	70.		
total	518.	total	518.

ORGANIC N	in		out
immobilisation	93.	mineralisation	153.
faeces	37.	surplus	47.
grazing/harvesting losses	70.		
total	200.	total	200.

N BALANCE ANIMALS (kg ha^{-1} yr^{-1})

	total	grass	maize	concentrates	type (%N)
intake	237.	235.	0.	2.	1.47
	total	urine	faeces	milk/meat	
excretion	237.	140.	50.	47.	
field	158.	116.	42.		
stable	32.	23.	8.		

INPUT/OUTPUT TABLE N (kg ha^{-1} yr^{-1})

INPUT		OUTPUT	
deposition	45.	milk+meat	47.
mineralisation	153.	leaching	45.
fertiliser	250.	volatilisation	15.
maize+concentrates	2.	balance loss	38.
		slurry	32.
		silage	73.
		organic N pool	200.
total	450.	total	450.

P BALANCE ANIMALS (kg ha^{-1} yr^{-1})

	total	grass	maize	concentrates
intake	30.6	30.1	.0	.5
	total	manure	milk/meat	
excretion	30.6	22.3	8.2	
field	18.6			
stable	3.7			

INPUT/OUTPUT TABLE P

INPUT		OUTPUT	
deposition	.9	milk+meat	8.2
fertiliser	.0	slurry	3.7
maize	0.	silage	10.1
concentrates	.5	accumulation	-20.6
total	1.4	total	1.4

DETAILS OF URINE AND FAECES PATCHES

	part	dry matter	N urine	N faeces	N upt.	% N	NO_3	K urine	K faeces	K upt.	% K	desired % K
U0F0	.7111	11480.	0.	0.	353.	3.20	25.	0.	0.	296.	2.68	3.11
U0F1	.0255	11480.	0.	1171.	353.	3.20	25.	0.	474.	467.	4.23	3.11
U0F2	.0005	11480.	0.	2342.	353.	3.20	25.	0.	948.	494.	4.48	3.11
U1F0	.2169	12173.	382.	0.	446.	3.80	81.	502.	0.	471.	4.01	3.40
U1F1	.0078	12173.	382.	1171.	446.	3.80	81.	502.	474.	537.	4.58	3.40
U1F2	.0001	12173.	382.	2342.	446.	3.80	81.	502.	948.	603.	5.14	3.40
U2F0	.0331	12394.	763.	0.	513.	4.30	13.	004.	0.	541.	4.53	3.63
U2F1	.0012	12394.	763.	1171.	513.	4.30	213.	1004.	474.	606.	5.08	3.63
U2F2	.0000	12394.	763.	2342.	513.	4.30	213.	1004.	948.	672.	5.63	3.63
REST	.0038	12511.	1172.	48.	556.	4.61	370.	1541.	20.	618.	5.12	3.78
av.	1.0000	11667.	116.	42.	379.	3.39	45.	153.	17.	349.	3.11	3.20