307

MAMBO 2.x

Design principles, model structure and data use

werkdocumenten

G. Kruseman, H.H. Luesink, P.W. Blokland, M.W. Hoogeveen and T.J. de Koeijer

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MAMBO 2.x

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Abstract

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This report describes MAMBO, the model for calculation of manure and fertilizer distribution based on economic principles. Six key processes regarding animal manure and artificial fertilizer are included in MAMBO: (1) Manure and mineral production on farms; (2) Maximum allowed application of manure on farms within statutory and farm level constraints using micro-simulation and mathematical programming techniques; (3) Manure surplus at farm level (production minus maximum application amount); (4) Manure distribution between farms (spatial equilibrium model); (5) Application of manure and artificial fertilizer within the remaining bounds resulting in soil loads with minerals; (6) emission of ammonia and other pollutants at all stages described above. MAMBO is a complex model that uses large amounts of data, the structure of the model and the data used as well as examples of key model results are included. Finally both design principles and quality control are discussed at length.

Keywords: manure, micro-economic simulation model, spatial equilibrium model, ammonia

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1 Introduction and objective

Introduction

At the beginning of the 1980's, LEI started with the development of the 'Manure model'. MestAmm, the model used from 1989 to 1997, was replaced by MAM in 1997 which was used till 2005. Problems faced by farmers with the removal of manure from farms and the related problems of acidification and eutrophication, made the model an important instrument for policy evaluation and research. The model has been used extensively for the evaluation of policy measures and to monitor the manure streams and the emission of ammonia.

Due to technical limitations of the MAM model and difficulties to incorporate significant changes in policy measures, it was decided to develop a new manure model called MAMBO. Construction of MAMBO started in 2004 and was completed in 2006 and this version of MAMBO, namely 1.x has been used till 2010. Technical documentation is available (Kruseman, 2009). The minor technical changes between versions 1.0 and 1.9, the last of the 1.x versions, have been documented separately (Kruseman and Blokland, 2010). With the advent of new advances in science with respect to ammonia emission calculations and important changes in manure legislation a new version of MAMBO was necessary. This version 2.x included a switch to a better model architecture (Quality Based Generic Modelling QBGM, Kruseman, 2010). This report gives an overview of all important elements of the current model. It includes main elements of the 2009 version of this documentation concerning MAMBO 1.x (Vrolijk *et al.,* 2009a) and all the new features of MAMBO 2.x. Future developments of MAMBO have been documented elsewhere (De Koeijer et al, 2012)

Objective of the report

The objective of this report is to give a thorough and clear description of MAMBO to provide insight in the functionality, the assumptions and the structure and logic of the model.

Structure of the report and advice to the reader

Chapter 2 gives a description of the historical development with respect to problems related to manure and minerals. Chapter 3 gives an overview of the design principles and assumptions applied in the development of MAMBO. Chapter 4 describes the model in general terms. The main processes related to the production, transport and application of manure and minerals are described. Chapter 5 provides a detailed description of the calculations and procedures in the different modules of the manure model. Chapter 6 focuses on the data required to run the model. The output of the model and the applications are described in Chapter 7. In Chapter 8, the important aspects of quality control of the model are described. The report ends with some final remarks and future developments (Chapter 9).

Readers who are interested in a general overview of the model can focus on Chapters 2, 4 and 7. Readers who want to develop an understanding of the more technical details with respect to the model processes and data requirements are recommended to also read Chapters 5 and 6. Table 1.1 gives an overview of information requests and the chapters to read.

Table 1.1: Advise to the reader

Information request	**Chapters to read**
What are the main ideas of the model?	Chapter 2 and 4
How does the model calculate in detail?	Chapters 4 and 5
What can I do with the model?	Chapter 3 and 7
Based on which data are the calculations made?	Chapter 6
How is quality of the model controlled ?	Chapter 8

2 Manure and minerals in The Netherlands: a historical perspective

2.1 Introduction

Animal production has been related to environmental issues since the early 1970's (Oenema, 2004). Eutrophication (pollution of surface and ground water with nitrogen and phosphate) and acidification (mainly ammonia emission) are important side effect of the production and application of manure. Besides national policies, European legislation increasingly affects policy measures around the production and application of manure. Section 2.2 gives a historical perspective on problems and policy measures related to manure. Section 2.3 describes the developmental pathway of manure models within LEI, from its predecessors to the newest model 'MAMBO'.

2.2 Manure related problems and policies

Since the beginning of the 1980s, problems related to manure surpluses have been an important item on the Dutch policy agenda. Intensification of animal farming, and in particular the increase in the number of animals on pig and poultry farms without own land, lead to manure production which exceeded manure demand by crops (Oenema, 2004). During the second half of the 1980s, an additional problem emerged: ammonia emission going along with the production and application of manure led to the acidification of soil, air and water. A policy aim of the Dutch government at that time was to reach a balanced manure market in 2000, implying that manure production capacity should be equal to manure application capacity. The achievement of this goal has been delayed. The aim now is to reach a balanced manure market in 2015. One way to achieve this aim is to reduce the manure production capacity. As a result, the government bought out manure production rights.

In later years, also European legislation had a big impact on the manure policy. The European Nitrate Directive (91/676/EEC) states that member states must identify zones vulnerable to nitrate leaching. A code of good agricultural practice had to be established and an action program concerning the vulnerable zones must be formulated and contains restrictions on manure application (Frederiksen, 1995). The Netherlands have been monitoring groundwater bodies for years, and an increasing number of extraction points exceeded the allowed 50 mg of NO_3 (De Walle and Sevenster, 1998). The Dutch government decided, therefore, to designate their whole territory as a vulnerable zone. A direct implementation of the manure application restriction would thus affect all farmers and would lead to a serious cutback in cattle, pig and poultry production. As a replacer of this general approach, MINAS was introduced in 1998 as a policy measure to be able to individually address nutrient management on farms and in this way to comply with the European Nitrate Directive. MINAS is a 'farm-gate balance approach' that calculates the difference between nutrients entering and leaving the farm 'through the farm gate'. Figure 2.1 gives a graphical overview of the system.

Only nitrogen and phosphorus entering (input) and leaving (output) the farm through the farm gate were taken into account, while the farm itself was considered as a black box. The difference between N and P inputs and outputs is called the farm surplus of N and P. The surplus is assumed to be lost to the environment. The surpluses are regulated by comparing them to environmentally safe surplus standards, also called levy free surpluses (LFSs). If the farm surplus exceeds the LFS, the farmer will be taxed for every kilogram of nitrogen or phosphate exceeding the LFS. Introduction of MINAS as a policy measure led to considerable reductions of nitrogen and phosphate surpluses.

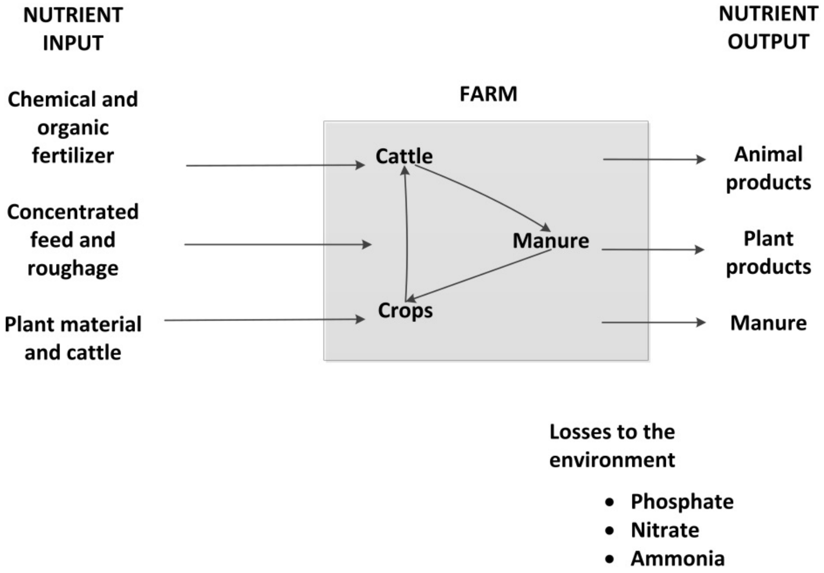

Figure 2.1: The concept of MINAS, considering the farm a black box (based on Wossink, 2000).

The European Court of Justice decided, however, that MINAS was insufficient as a policy measure to comply with the European Nitrate Directive, due to possibilities to buy off the environmental pollution. The most important reason to dismiss MINAS was that MINAS was based on norms of mineral losses rather then on application norms. In order to comply with the European Nitrate Directive, a new nutrient policy measure of application came into effect in 2006. In this new policy Dutch farmers will have to comply to maximum application standards for different types of fertilizer. There are three application standards: (1) for the total volume of animal manure; (2) total working nitrogen application; and (3) total phosphate application.

The application standard for animal manure is expressed in kg of nitrogen per hectare. The standard is either 170 kg or 250 kg. The first standard is laid down in the European Nitrate Directive, the second is a derogation norm that applies to some farms with mainly grassland.

The nitrogen application standard for total nitrogen application concerns the sum of chemical nitrogen fertilizers and active nitrogen in animal manure and active nitrogen in other organic fertilizers. The standard differs per crop. The phosphate application standard concerns the total application of phosphate from chemical fertilizers, animal manure and other organic fertilizers. The standard differs for grassland and arable land. The level of the application standards will be reduced gradually over the coming years.

The system of application standards in The Netherlands replaces MINAS. This means that farms are no longer assessed on the amount of nitrogen lost into the environment (output), but on the amount of nitrogen they apply for growing crops (input). The down side is that farms are less able to tailor their management systems to meet the environmental objectives as was the case with MINAS. This means that the system became more of a “one-size-fits-all” and that farmers could not benefit from specific management practices. Over the next few years after the introduction of the new system application standards become more and more tailored to individual farm circumstances. With the CAP reform of 2013 this type of approach will also be advocated by the EU and it is foreseeable that by 2020 support to agriculture will be based primarily on individual farm performance on public indicators such as local environmental pressure.

Ammonia emissions

In 2001, The Netherlands agreed to comply with emission ceilings for sulphur dioxide (SO_2), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOC) and ammonia (NH_3) under the

National Emission Ceilings (NEC) Directive by 2010 in order to abate acidification and air pollution. Achieving the national emission ceilings in 2010 (and later years) will have a positive effect on air quality and therefore on health and the environment. With regard to air quality, countries wishing to derogate from EU air quality requirements (in this case, particulate matter and NO_2) must report to the Commission on the implementation status of the national emission ceilings.

The national emission ceiling for ammonia is 128 kilo tonnes. The PBL (Dutch Environmental Assessment Agency) forecasts emissions of 126 kilo tonnes in 2010. Measures are being taken to cut ammonia emissions. One example is the urea target of the dairy sector of 20 mg ammonia per liter of milk by 2010. Another important measure is the use of emission low housing systems. Emission reduction can also be achieved by using air scrubbers (Melse *et al.,* 2006). The Dutch government is currently pushing for large-scale introduction of these scrubbers on poultry and pig farms and also on new stables for cattle. Below is an overview of more established policy for agriculture with respect to the reduction of ammonia emissions (Table 2.1).

Table 2.1: Overview of measures for ammonia emission reduction in agriculture

Policy
Compulsory use of manure storage covers
Compulsory low-emission application of manure to land
Low-emission housing (order in council on livestock housing)
Use-standards (manure policy)

2.3 Background and objectives of the MAMBO model

The domain can be schematized as follows. There are a large number of farms which have animals that produce manure and farms have crops on which manure can be applied. There are different categories of farms. Some farms, intensive livestock farms, only have animals which produce manure (farm P in Fig. 2.2). All manure should be removed from the farm. Other farms, specialized crop farms, have crops but no manure produced on the farm (farm Y in Fig. 2.2). These farms can apply manure from other farms. Furthermore there is a large group of farms that produce manure and also have crops on which manure can be applied. Some of these farms produce such a large amount of manure that it cannot be applied on their own lands (farm x in Fig. 2.2). Other farms have only a small production of manure and can still use manure from other farms (farm z in Fig. 2.2).

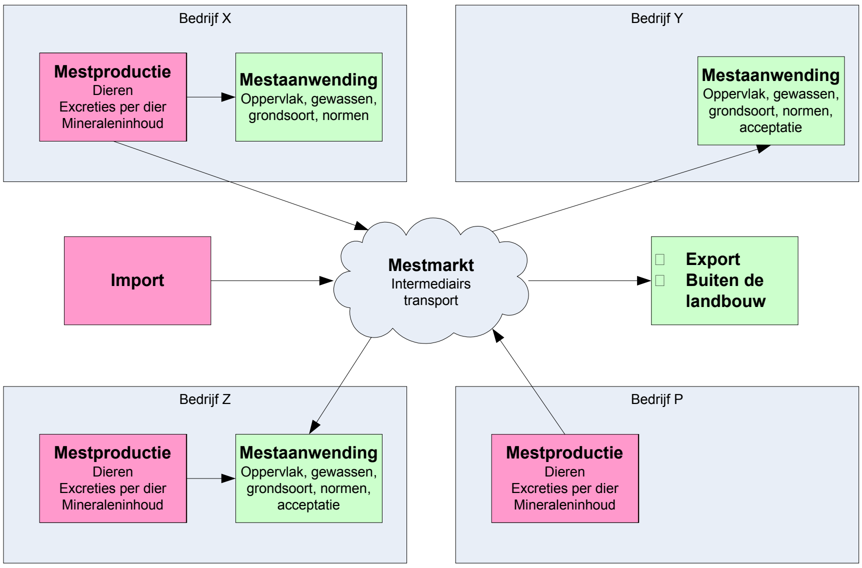

Figure 2.2: Manure market

Looking at the current situation in the Netherlands it is important to realize that a large share of the produced manure is used at the own farm (Luesink *et al.* 2008a). Only a limited share is transported of the farm. There are however large differences between types of manure. Of the manure of dairy cows and other grazing animals only a small share is traded on the manure market. In contrast, almost all chicken manure and pig manure is traded on the manure market (Figure 2.3).

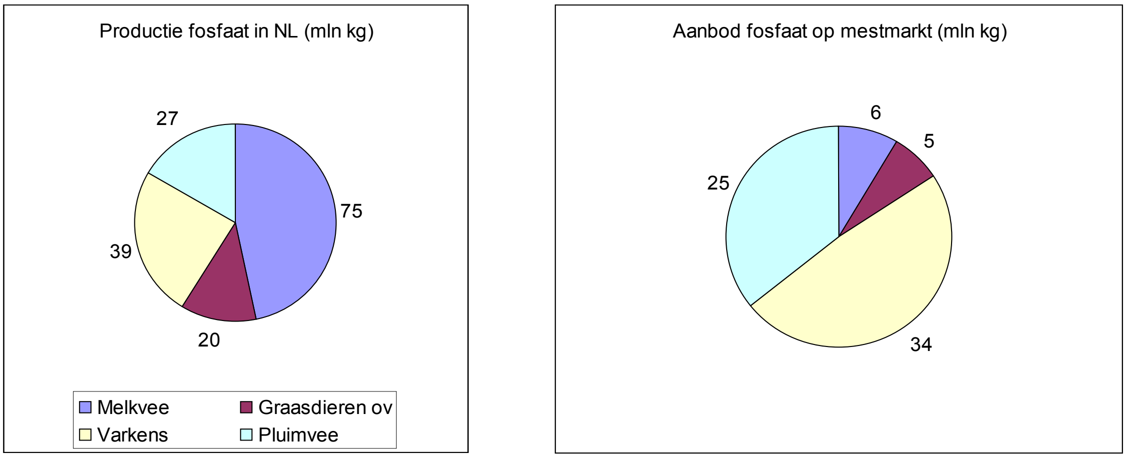

Figure 2.3: Production and marketing of manure in the Netherlands 2006 (Luesink et al. 2008a)

Some farms need additional manure for their crops and some farms need to transport animal manure from their farm. This supply and demand come together on the manure market. This market partly consists of direct transactions between individual farmers but a large share of the market is organized by intermediates, the manure transporters. The market consists of a large number of suppliers and demanders. The market is however not very transparent (De Hoop *et al.*, 2011) which causes high transaction costs and non-optimal solutions (from a social welfare point of view).

The challenge for a farmer is to find a cost effective way to produce crops by applying minerals to the crops and to store or transport a possible overproduction of manure. From an agronomic and farm economic point of view this is already a complex question. The question becomes even more complicated because policy measures affect the production and application of minerals.

Agricultural production has different external effects. Not only the direct economic products are produced (animal or crop products), but also unwanted side effect occur (amongst other ammonia emission, leaching of minerals in surface and ground water etc. (Kruseman *et al.* , 2008). These can have extensive effects on public health, the environment and nature. Therefore European and national governments design policy measures to limit the impact of these side effects. Depending on the type of measure these measures affect the animal production (e.g. animal production rights) or the application possibilities of manure (e.g. limits on the amount of minerals that can be applied on crops).

Changes in policies can affect the choices of farmers and therefore the agricultural structure. In designing policies, questions arise how the measure affects the production and application of manure and therefore the possible distortion of a balance on the manure market. Furthermore changes in policies affect emissions from agriculture. To assess the impact of policies in combination with other developments an integrated framework is needed. Mambo provides such an integrated framework, which brings together agronomic, technological and economic knowledge to quantify the impact of external developments, technical changes, and policy measures on the production of manure, the application of manure and emissions related to these topics. For the agronomic and technological knowledge extensive use is made of research done by other institutes of Wageningen UR. Mambo is a static model. To incorporate structural changes, MAMBO cooperates with a partial equilibrium model called DRAM (Helming, 2005; see section 7.4.3).

2.4 MAMBO in relation to other manure and ammonia models

Predecessors of MAMBO

Already in 1982 LEI started with the construction of a model for the calculation of technical and economical aspects of manure distribution and processing (Manure model). Financed by the precursor of FOMA 'Commission on prevention of nuisance from livestock farms', this research yielded the first model in 1984 (Wijnands and Luesink, 1984).

With research guided by FOMA at the end of the 1980's, an ammonia emission model was constructed by the LEI (Oudendag and Wijnands, 1989). In that year also the second manure model was finished (Luesink and Van der Veen, 1989). In the beginning of the 1990's both models were combined to the first LEI manure and ammonia model called *MestAmm* (Brouwer *et al.*, 2001; Oudendag and Luesink, 1998).

In 1996 LEI started with the construction of the second generation of the Manure and Ammonia Model (MAM). It included variant and version management and was finished in 1998 *(Groenewold et al.*, 2001, 2002).

Late 2004, LEI started with the third generation of the manure and ammonia model for policy support (MAMBO). This generation was finished in 2007. MAMBO allowed the scientific decoupling of emission data and their origin, thus allowing the calculation of the national emission values using locally generated data. In 2011 the second generation MAMBO models became operational with improved model architecture and more features including state-of-the-art ammonia emission calculations and the possibility to deal with tailored policy instruments directed at farm specific circumstances such as soil Phosphate state differentiated P norms.

It is eminent that in the near future, the gathering of data sources and application of calculation protocols regarding ammonia emissions will receive international attention. Harmonization of the complete process should become an integral part of the EU agenda. This is started already with the European Agricultural Gaseous Emissions Inventory Researchers Network (EAGER) (www.eager.ch/).

Other models

Within Europe different models exist for modelling manure transport and ammonia distribution.

1. Primal Transportmodel (Campens en Lauwers, 2002) is a manure transport module with the objective to minimize transport costs on district level. Manure application options within the importing and exporting district is taken into account on the basis of crop production and the produced amount of own animal manure.
2. MTA (Manure Transportation and Application Model) (Keplinger en Hauck, 2006): Manure transport and use of manure are computed based on mineral content, mineral availability ratio, crop needs, nutrient level of the soil, manure application and –transport costs and prices of artificial fertilizer. Objective is minimizing the application costs of manure, which include transport costs.
3. MITERRA (Lesschen *et al.*, 2009, 2011; Van der Hilst *et al.,* 2012; Velthof *et al.,* 2009a) calculates nitrogen and phosphate surplusses and emissions of ammonia and greenhouse gases.
4. Initiator (Kros *et al.,* 2005; Kros *et al.*, 2011) is a relative simple model that calculates the important N-fluxen on regional level. The model takes into account: the amount of Nitrogen from manure and fertilizer, nitrogen deposition, uptake of N by crops, emission of NH_3, N_20, NO_x and leaching and run off of N to ground- and surface water.

Other models focus on the emission of Ammonia

5. MAST: Model for Ammonia System Transfers at the farm scale (Ross *et al.*, 2002) is a Farm model for dairy farms containing five modules in which emissions during grazing, housing, storage, application of animal manure and application of artificial fertilizer are modeled. The

model requires limited input of data which contributes to the user friendliness. The effect of changes in application techniques, diet and grazing time are modeled.

6. DYNAMO (Dynamic Ammonia Emission Inventory) (Menzi *et al.,* 2003) is a Swiss model for computing the ammonia emissions on farm and national level. The model computes ammonia emissions as a percentage of the amount of nitrogen present in each step of emission.
7. DanAm (Hutchings *et al.*, 2001) is a Danish model that on national level models the geographic distribution of ammonia emissions originating from animal manure, artificial fertilizer and crops on one squared kilometer grid cells.
8. GAS-EM is a German model computing ammonia emissions on national and district level (Reidy *et al.,* undated)

Other models go a step further in quantifying the impact of measures to reduce ammonia

9. MARACCAS (Model for the Assessment of Regional Ammonia Cost Curves for Abatement Strategies) (Cowell en Apsimon, 1998) models the flow of Total Ammonia nitrogen (TAN), the emission in each step of production and the cost effectiveness of (a combination of) emission reducing measures. The cost effectiveness of each measure is made dependent on (the combination of) other measures taken. The model is applied for each European country.
10. NARSES_EM (National Ammonia Reduction Strategy Evaluation System for Emissions) (Webb en Misselbrook, 2004). British model with identical working principals as MARACCAS. The difference with MARACCAS is that NARSES_EM is integrated with a special information system which provides the model input. This way, local differences in animal numbers and type of farm management is taken into account. The end result is a GIS map with which the cost effectiveness of measures can be modeled.

Mambo focuses on the emissions points. Other models also include the athmospheric distribution and deposition.

11. RAINS model (Regional Acidification INformation and Simulation) is a European model that pictures the atmospheric distribution of acidifying and eutrophying pollutants, the sensitivity of and risks for human and ecosystem and the cost-effectiveness of reducing strategies (MNP, 2006a).
12. TERN model (Transport over Europe of Reduced Nitrogen) (ApSimon *et al,* 1993) is developed to simulate the atmospheric distribution and the delivery of ammonia. The model uses detailed resolution for an exact ammonia concentration profile. The model also simulates the distribution of an air column which is divided in several air layers.
13. RADM (Regional Acid Deposition Model) (NAPAP, 2005) forecasts changes in deposition due to changes in nitrogen emission, forecasts the impact of emissions in one areas to the acidifying deposition in other areas and forecasts the level of acidifying deposition in areas sensitive to acidification.
14. RPM (Regional Particulate Model) (NAPAP, 2005) is an expansion of RADM in which also the chemical characteristics and dynamics of atmospheric aerosols is taken into account.
15. EMEP (European Monitoring and Evaluation Programme) (Berge en Tarrason, 1992) is a Langrangian model suitable for measuring concentrations and depositions of gasses, inclusive of long-range transmissions for air pollutants in Europe.
16. OPS-SRM (Operational Priority Substances – Surface Response Model) (Jaarsveld, 2004) The latest version of the Operational Priority Substances (OPS) model. OPS is a model that simulates the atmospheric process sequence of emission, dispersion, transport, chemical conversion and finally deposition. The model is set up as a universal framework supporting the modelling of a wide variety of pollutants including fine particles but the main purpose is to calculate the deposition of acidifying compounds over the Netherlands at a high spatial resolution, including the link between ammonia emissions and nitrogen deposition. The SRM version is a meta model of the complete process based OPS-PRO model which can calculate much faster with minimal loss of certainty (see Section 7.3 for details on linkages with MAMBO).

3 Design principles, assumptions and demarcation

3.1 Introduction

This chapter explains the background of MAMBO. It starts by giving an overview of the decision making process in which it was decided to develop a new model. Furthermore the chapter describes the design principles, assumptions, and demarcation of the model domain.

The history of manure and mineral flow modelling at LEI for policy assessment was described in detail in Chapter 2. The previous MAM model has been applied successfully for a range of years. The model was however not easily adjustable to the major changes in the manure and mineral policies. Therefore it was decided to redevelop the model in a new software environment that would ensure the continued use of the model for policy analysis.

In 2002, an analysis of the situation revealed that the model available at that time (MAM) was unable to deal with a number of issues (Bouma *et al.,* 2002). These issues covered changes in the manure policies as well as developments in modelling and software engineering. A list of desired functionalities was developed ranging from very specific policy instruments that the model could include, to more general functional specifications to technical requirements concerning the software, data output etc.

In 2008 when MAMBO was operational for a little more than a year, a review of MAMBO conducted by an external committee (Oenema, 2008) where certain shortcomings in the development and implementation were noted. These shortcomings have been addressed together with the incorporation of advances in science and updates to accommodate changes in manure and mineral policy.

In 2010 MAMBO obtained WOT model status A in a long process in which additional requirements were posed to the model. Finally MAMBO is a core LEI model that is under constant scrutiny of the LEI internal model audits that impose constant upgrading of quality measures.

3.2 Original objectives of the revision of the previous model

The main objective of the revision of the model is to ensure the continued use of the model for policy analysis while providing results that can be compared with the results from previous models (MAM).

Due to the changes in the manure policies it was necessary to introduce a number of new aspects in the model. Examples of requirements, which were partly dependent on changes in manure policies were:

- Different types of grassland;
- Norms that are dependent on soil type;
- Farm level data on soil type, mineral content and stable types;
- Inclusion of derogation;
- Use of artificial fertilizer (phosphate and nitrogen);
- Urea content of milk;
- Generate output on a regional level;
- Use of parcel information;
- Inclusion of other manure related elements / substances;
- Inclusion of different grazing systems.

Besides objectives related to the model domain, a number of secondary objectives of the revision were defined:

1. Ensure transparency of the model (architecture, structure, data flows, model code);
2. Abide by quality standards of models;
3. Backward compatibility;
4. Forward flexibility.

Important considerations with respect to the revision objectives are:

- The choice of software environment;
- Consistency with other models at LEI;
- Strict separation of data and processes;
- Flexible levels of aggregation;
- Flexible use of input data;
- Conceptual separation of processes and policy;
- Processes are generic including exceptions to general rules;
- Flexible output both for end-users and model interfaces;
- Flexibility in index classifications;
- Explicit quality control.

Therefore it was decided to redevelop the model in a new software environment to ensure that these objectives could be met. One should note that while the objectives have been clear from the outset, the guiding principles on how to reach these objectives have changed in the course of the process of developing MAMBO.

The objectives of MAMBO imply that the model is flexible and transparent. Flexibility commonly leads to higher levels of complexity and complexity has a trade-off with transparency. While this is true we have adjusted our design principles in the course of model development to ensure both seemingly contradictory aims.

3.3 Design principles

The design principles we apply in MAMBO are general and generic. They are consistent with standards of good modelling practice:

- Readability (semantics);
- Readability (syntax);
- Separation of data and calculations;
- Comments and documentation;
- Model efficiency (syntax for speed);
- Sparse modeling (syntax for error free updating).

The specific design principles for MAMBO other than those related to general good modelling are highlighted below.

3.3.1 Consistency with other models

Within the LEI other models are available to evaluate agricultural and environmental policies. Consistency with other models is achieved by using the same modelling language and the same user interface for interacting with these models (*e.g.* Dutch Regionalised Agricultural Model, DRAM (Helming, 2005)). The structure of the model should be such that data that needs to be exchanged between models interfacing with MAMBO can have a broad scope. The underlying assumption, based on modelling experience, is that in general models have difficulty communicating with the outside world. In MAMBO we try to have an open line of communication both at the input and the output side.

The responsibility for consistency with other models is assumed by MAMBO because MAMBO is aimed at being flexible. In terms of data formatting MAMBO should be flexible.

Consistency does have its limitations. If there are incompatibilities between available input data and desired output (in both cases in terms of concepts and / or classifications), that cannot be solved with translation rules, the inconsistency between the two models with which MAMBO is trying to communicate will form a bottleneck.

3.3.2 Flexible level of aggregation

The model should be able to run at different aggregation levels. The aggregation level can be dependent on the type of research question but also on the availability of data. Also at the output side, it should be possible to generate data at different levels of aggregation. Differentiation of aggregation levels both spatial and temporal is needed because data can be available at different levels of aggregation. The modelling system should allow exogenous data defined at a specific level of aggregation to be used at a different level of aggregation using well-defined aggregation and disaggregation rules. Definitions of the levels of aggregation should be flexible.

3.3.3 Flexible use of available data

The model has been designed in such a way that it can incorporate different types of information. The current version of the model runs on information at farm level, but other levels are possible. In case of information available at establishment level, or parcel level or even animal level these data could be incorporated in the model.

The model should also be able to deal with data from different sources. Explicit methods should be included to deal with consistency between different data sources.

3.3.4 Dependency on underlying processes not policies

The core of the model should be independent of the current policies. The core of the model consists of the processes related to the production, application and transportation of manure and minerals. These processes are persistent and do not change due to policy changes. However, a policy change can have an impact on the extent to which certain processes take place and can even abolish some relevant processes (for example the export or processing of manure).

Policy options and scenario assumptions are kept outside the core of the model in order to provide a robust and stable core of the model. It also makes more transparent which assumptions are used in a scenario because the assumptions are not hidden in the core of the model but are specified in the interface. Policy and scenario assumptions are treated in the same way as data, *i.e.* separated from the model code, imported into the model as exogenous information flows.

3.3.5 Modelling of underlying processes not exceptions

Model processes not exceptions has two aspects. The first aspect is in the design of the model the second is in the implementation. In the design of the model a level of abstraction is chosen in which processes are as generic as possible. Starting from exceptions results in an unnecessarily complex model. Designing the model in a proper way can therefore preclude the necessity to include exceptions in the model implementation. If, however exceptions are still relevant in the implementations, these exceptions should not be hard-coded, but rather be introduced as generic exceptions that are switched on and off with user defined settings. Within this framework, exceptions can be set to turned-off state as default.

3.4 Demarcation

Demarcation of a model places boundaries on its scope. Within these boundaries the model is valid. Note that the demarcations highlighted in this section are valid for the current version of MAMBO only. If necessary the demarcations can be extended if it becomes necessary in the future, but may require (substantial) changes of MAMBO.

The overarching demarcation of MAMBO is the realm economic aspects of manure and minerals from fertilizers in the agricultural sector. Notwithstanding the economic focus of MAMBO it has some important and even critical cross-references to biophysical sciences. The main demarcations of the model refer to this area.

The first demarcation is at animal level. Manure production happens under the tail. The model starts with the excretion of manure and minerals from the animals. Some characteristics are used to choose the correct excretion parameters, but the processes that determine the excretion are not modelled in MAMBO. MAMBO makes use of the outcomes of such zoo technical process models in terms of technical coefficients.

The second demarcation is the application of manure and minerals at the field. Further processes are not included in the Manure model. The outflow to the surface and ground water is modelled by other models, such as STONE. Crop growth models to link growth factors such as plant nutrients to primary vegetative production are also not included. MAMBO provides the application levels of manure as input into these models.

The third demarcation is the agricultural firm as decision making unit with respect to:

- Defining the application destination of manure and fertilizers on the farm;
- The decision to keep or dispose of manure;
- The decision to buy manure and fertilizers.

The household decision making rules while consistent with agricultural household theory, follow the logic used in MAMBO's predecessor MAM.

The fourth demarcation is the agricultural sector. For instance if manure is processed into manure products, the processes and their coefficients regarding inputs and outputs are taken as such, the industrial process itself is not modeled. In the spatial equilibrium model we do not consider general equilibrium effects of manure transport on the economy as a whole. Demand for manure, manure products, minerals, etc. from outside the agricultural sector is provided from exogenous sources.

The fifth demarcation relates to the temporal differentiation in the model. The model calculates results on an aggregate yearly basis. For some specific components smaller time steps or delimitations in time are used, but always in relation to the aggregate yearly basis. Specific temporal disaggregation using well defined rules (*e.g.* proportional disaggregation based on exogenous information), calculation at the disaggregated level and then aggregation to the yearly basis.

Having said this the structure of MAMBO is such that extensions beyond these demarcations can be envisioned. This is closely related to the design criterion of consistency with other models. Some of these extensions will need more than a trivial reconstruction, especially if the processes are to become an integral part of MAMBO.

The structure of MAMBO is such that zootechnical, agronomic (crop growth), physical outflow, and other technical process models can be linked to it or even incorporated as a special module if necessary. The structure of MAMBO is such that more elaborate agricultural decision models can be plugged in if necessary. Going beyond the agricultural sector may require two different approaches depending on the needs. The inclusion of process models related to processes outside the agricultural sector that have a bearing on what happens in MAMBO can be dealt with in a similar way as other technical process models discussed previously. The other approach relates to the general equilibrium effects of MAMBO. The theoretical problems of integrating the current state-of-the-art in simulation modeling and general equilibrium modeling are not completely solved in the scientific world.

3.5 Additional needs

The review of CDM in 2008 mentioned earlier had four main conclusions that were taken into account in further development of the model.

1. Recognition of the importance of sensitivity analysis and validation studies;
2. The need for transparent and up to date technical documentation;
3. Confirmation of validity of the model through publication in peer reviewed journals;
4. Ensure sufficient involvement of stakeholders (financers, model result users, domain experts) in the development, organization and implementation of MAMBO.

3.6 Assumptions of current version

In the current version, the agricultural sector is described by the agricultural census. The characteristics of the agricultural census are therefore important for the results of the manure model. The model has been structured in such a way that it is relatively easy to base the model on other data sources when available (more detailed or less detailed). Additional data from other sources that are linked to the base data based on the agricultural census do not have primacy. The basis is always the agricultural census.

In the current version the common element linking different procedures and modules within the modelling framework is manure quantity (demarcation number 1 in Section 3.4). This manure quantity has mineral contents and this content can change (be updated in the course of the model due to losses and emissions). Just as manure can change if processed. Mass balance is maintained however.

The level of detail in the model can vary depending on the goal of the research project or the availability of data.

The transportation model minimizes the costs at national level. In the current version of MAMBO the level of aggregation in the spatial equilibrium model are regional areas. This is done to ensure consistency in calculation procedures between MAM and MAMBO.

In the current version of MAMBO an exogenous manure price is used. The source of this manure price is undetermined and could be based on either historic data, expert knowledge or model results of models that use market conditions of supply and demand for manure and minerals to determine price.

4 Conceptual model

4.1 Introduction

This chapter describes the design and structure of the model in general terms. For a more detailed description of the model and the data we refer to Chapters 5 and 6.

By the development of MAMBO, a generic formulation was chosen to facilitate the use of data with a deviating structure (i.e. animal categories, crops, manure categories, housing types). Furthermore, adjustments to incorporate the policy concerning manure and emissions in MAMBO were made.

MAMBO can be used to calculate both nutrient flows and ammonia emissions (Figure 4.1). To implement this, five key processes regarding animal manure are included in this model:

1. Manure production on farm;
2. On farm maximum allowed application of manure within statutory and farm level constraints;
3. Manure surplus at farm level (production minus maximum application amount);
4. Manure distribution between farms (transport);
5. Application of manure resulting in soil loads with minerals.

The calculations take place at three spatial levels. The first three processes are calculated at farm level, whereas manure distribution is calculated at the level of 31 predefined manure regions, and soil loads are calculated at municipality level. These five key processes are described in further detail, prior to dealing with ammonia emissions on the basis of the three spatial levels in the following sections.

4.2 Manure production

Manure produced on animal farms can be classified and processed separately in the MAMBO model. Sources of manure are distinguished based on the following parameters:

1. Type and number of animals kept on the farm;
2. Type of feed given to the animals;
3. Housing facility (yes = housed, no = pasture);
4. Type of housing facility used.

The manure can be excreted directly on the field, it can be stored or it can be processed at farm level into other products, such as dried manure or separation products, each with its specific ammonia emission characteristics.

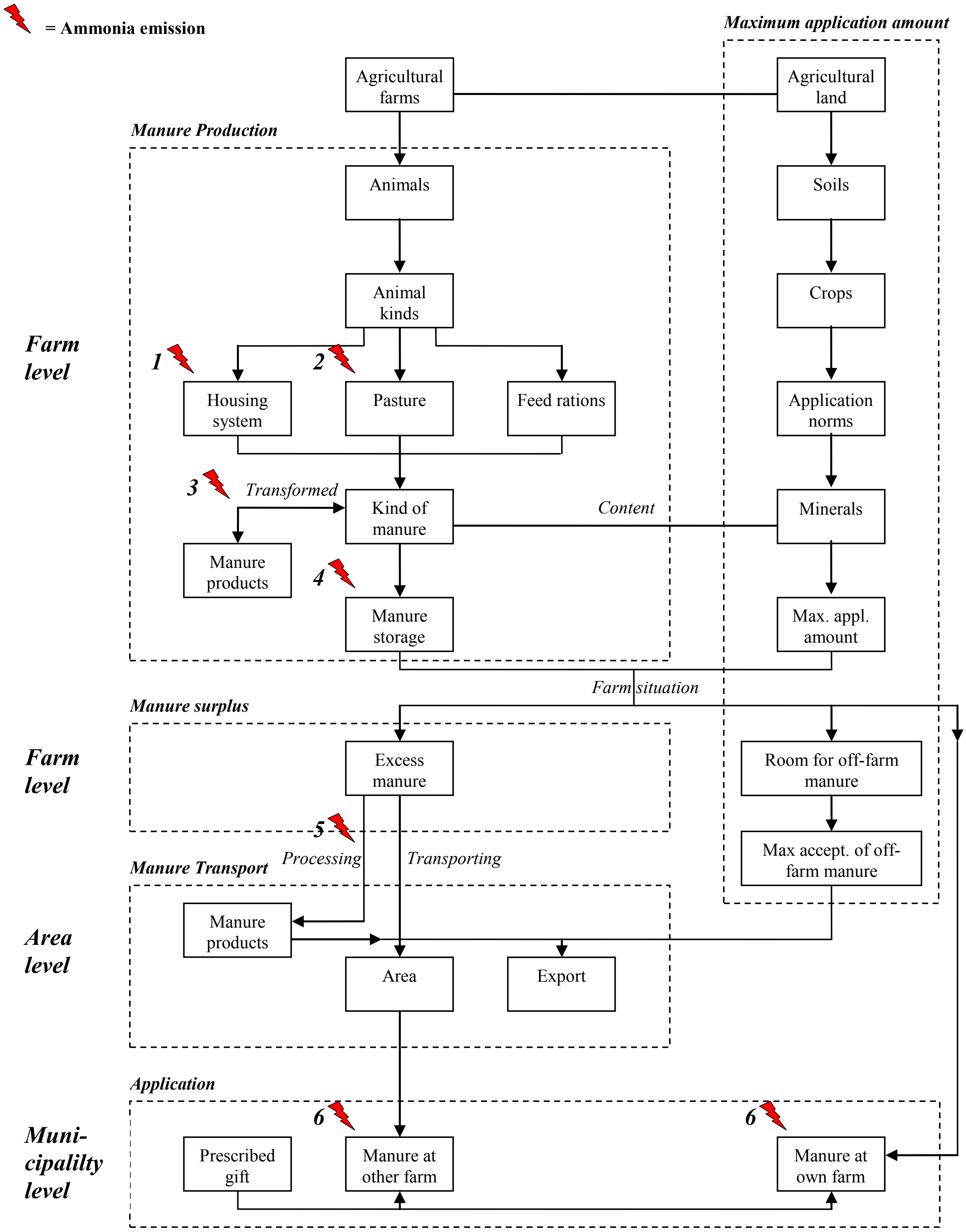

Figure 4.1: The Manure and Ammonia emission Model (MAM/MAMBO).

4.3 Maximum application amount

MAMBO includes three factors determining the amount of manure for the application of on-farm manure: the total crop area of the farm, the type of crops grown on the farm, and the statutory application standards. The statutory application standards prescribe the maximum amount of nitrogen and phosphate allowed to be applied for each crop and soil type.

A farm with more manure production than its maximum application amount can still accept off-farm manure in cases where the on-farm manure is not suitable or economical for the type of crops grown on the farm. A larger part of the on farm produced manure then has to be transferred to other farms to avoid surpluses.

4.4 Manure excess at farm level

There are several ways in which manure, either processed or unprocessed, can be used. It can be applied on the land of the farm where it is produced, stored or transported to other farms. Furthermore, there are a number of conditions for the manure production by animals kept on pasture. Firstly, pasture (grassland) needs to be part of the cropping plan of the farm. Secondly, manure from pasture can neither be transported nor processed. Thirdly, the manure production from pasture may not exceed the statutory application norms for grassland of the particular farm.

In order to determine whether a farm has a manure surplus or room for off-farm manure, the manure produced on the farm is balanced against the maximum application amount of manure on the farm. In case of a manure surplus, the economic consequences of the surplus are minimized by finding the most appropriate type of manure for each particular farm.

The maximum amount of off-farm manure applicable on a farm depends on the farmer’s willingness to accept off-farm manure and on the actual maximum application amount. In normal life, this is determined by the nutrient requirements of the crops grown on the farm, the region and the price of manure. In MAMBO, the willingness to accept off-farm manure depends on the type of manure and its’ mineral content and on the acceptation degrees.

4.5 Manure transport

MAMBO includes three options for manure that cannot be applied at farm level: it can be transported to other farms within the same region, transported to other regions or exported to other countries, either processed or unprocessed. Given the necessity for a farm to transport manure, the main driver for transport of any type of manure is minimizing manure transfer costs.

The combined data on farm total manure surplus, total application amount for off-farm manure, and the available options for manure processing and export, is used in the MAMBO model to calculate manure transfers within and between 31 predefined regions. The transfers are calculated in such a way that costs are minimized at national level. The costs consists of costs for transport, storage, application, processing and export.

Whether manure is transferred within the same region, to other regions, or exported depends on the transportation costs, the expected revenues of the manure and the maximum application amount for off-farm manure. Transportation costs within a region are fixed and depend on the type of manure and the type of application. Transport between regions is also dependent on the distance between the regions.

Transport costs are minimized within the scope of these basic assumptions:

1. Processing and export of manure may not exceed maximum capacities;
2. Regional manure mass balance: The sum of the total manure production of a region and the supply of manure from other regions must be equal to the sum of regional application of manure, off-farm manure and processing minus export and transport to other regions;
3. The manure transport into any region is equal or less than the available room for off-farm manure for that region;
4. Manure is transferred from other regions only if the regional surpluses are insufficient to fill up the room for off-farm manure;
5. Manure is transported into other regions only if it is in surplus, exceeding the maximum application amount for off-farm manure in the region of origin.

4.6 Soil loads with minerals

In MAMBO, the total mineral load of the soil depends on three factors: the application of on-farm manure, the application of off-farm manure and the application of mineral fertilizer. The Dutch farm accountancy data network provides data and statistics available about the use of mineral fertilizers at a regional level. These are divided at municipality level with a distributive code. The distributive code holds data on the time of manure application, the effectiveness of the nutrients and the amount of nutrients in the applied manure. For this purpose, the manure transfers on municipality level are calculated from the results of manure transfers on regional level by disaggregating these to municipality level.

5 Detailed model description

5.1 Introduction

General theories on models and modelling provide us with clear guidelines on the structure and development of models. Because of the complexity of MAMBO we opt to use a rigorous approach, taking components from systems analysis theory, general model theory and combining this with general principles on good modelling practices.

The conceptual model presented in Chapter 4 provides the context and the basic assumptions that guide the model development.

Theoretical models can be divided into two groups, both of which we use. The first consists of a system analytical approach where the aspects from the conceptual model are divided into systems and subsystems, each with their specific inputs, outputs and internal rules. Figure 4.1 summarizes this in general terms.

The second group of theoretical models consists of the mathematical representation of the issues at hand. This mathematical representation can be specific where possible and illustrative and general where necessary. A major portion of this part of the report is dedicated to the mathematical representation of the issues. In this chapter we present the general structure of the model based on the mathematical equations that guide the process.

Finally a computational model gives the specific details how the calculations are actually conducted based on the mathematical representation presented earlier. It should be clear that this hierarchy of models allows for a clear delimitation of expertise.

Before giving the mathematical representation of the relationships guiding the processes related to emissions from livestock and agriculture we will present a common vocabulary used throughout this chapter.

5.2 Common syntax and vocabulary

The syntax used in the equations is as follows. We have items that have descriptive super and multiple subscripts. An item is either a numeric variable (Table 5.3), or a parameter, or technical coefficient (Table 5.4) in the model. The subscripts contain the indices over which the item is defined. The subscripts are divided into three categories. The first relates to conceptual domains (Table 5.2) and the second to levels of aggregation (Table 5.1), the third that is only sporadically used is time. The superscript describes the domain of the item. An example is provided below:

$$\left(B^{Manure}_{ad^{p}f^{pm}|h}\right)$$

B stands for secondary production. The descriptive superscript indicates that it is manure. The indices over which it is defined are animal categories (a), pasture department categories (dp), pasture manure categories (fpm) at the aggregation level firm (h). So we are dealing with the variable pasture manure production.

The lowest levels that MAMBO takes into consideration are individual animals, plots or fields, stables, complete industrial processes (i.e. for manure processing). Although these individual items are the lowest level at which MAMBO can do calculations data is often unavailable at that level. Instead we use first level aggregations: All animals in an animal category, all plots and fields of a specific crop soil type combination, all stables of a specific department category, to name the most important examples.

It also accounts for interactions between parties handling manure through a spatial equilibrium model where suppliers of manure, *i.e.* livestock farmers with a surplus amount meet arable farmers with ample space for manure placement. The model calculates the transport of manure at municipality level and finally the placement of manure and additional artificial fertilizer are calculated at plot level on the farm.

The structure of MAMBO allows for calculations to take place at a higher level of aggregation if the available data and / or the policy or research question at hand deem it more appropriate. In this section the mathematical structure of relevant parts of the model that attribute to the calculation of ammonia emissions is presented.

The mathematical representation of the model equations follows the standards of the common vocabulary. The components of these equations are presented in a number of tables (Table 5.1 – 5.6). Tables 5.1 through 5.3 contain the indices or subscripts (Sets in GAMS terminology). The indices represent subdivisions of variables and coefficients at stake. These subdivisions are related to the level of aggregation of the variable or coefficient (e.g. region, municipality, farm, establishment) or a further specification of the variable it self (e.g. manure categories, crops, derogation). A special group of indices (described in Table 5.3) is used to define discrete steps. Discrete steps are necessary when policy divides otherwise continuous values into classes with bounds. It is also used for linear approximations of homogenous strictly convex non-linear relationships to be used in a linear programming framework. They are presented in alphabetical order.

Table 5.1a: Aggregation indices (spatial)

Indices		**Description**	**Alias**	**Range**
α		Animal of firm		{1}
c		Country		{NLD}
d		Department of firm		{1}
e		Establishment of firm		{1}
f		Field of firm		{1}
h		Firm (household)		variable[1]
m		Municipality in Regional area		variable[2]
n		Region in Country	N	{R1,R2}
p		Province in region		{P1*P12}
r		Regional area in province	R	{RA1*RA31}

Table 5.1b: Aggregation indices (temporal)

Indices		**Description**	**Alias**	**Range**
s		seasons		{winter, spring, summer, autumn}
t		time-span of the model (year)		

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[1] Firm registration codes that vary from year to year due to changes in firms.

[2] Because municipalities change due to administrative reshuffling, the number and identification of municipalities changes from year to year.

In Table 5.1 we can see that quite a few indices have a single element. In the case of α (individual animals of a firm or establishment), d (individual departments or stables of a firm or establishment), e (establishments of a firm), and f (individual fields or plots of a firm or establishment), the reason is the lack of complete and consistent data at that level of aggregation. All the data of that level is aggregated to a single unit. Although it is known that firms have a main establishment and subsidiary establishments, we only have data for the firm as a whole. Hence a firm is considered to have one establishment only. With respect to the other fore mentioned indices this is also the case. Fields merit special mention. There is data available linking each field with its coordinates and the crops grown on that field in a specific year to individual firms. However the data is not fully consistent with the base data from the agricultural census, hence we use the information from this data to some extent so that field refers to all land of a firm of a specific soil type with a specific crop (including pastures and fallow).

The index country contains only one element {NLD}, as MAMBO has been developed for the Netherlands. For full description of index elements see Chapter 6.

Table 5.2: Conceptual indices

Indices		**Description**	**Alias**	**Range**
a		Animal categories		variable
	a^d	Dairy animal categories		classification specific
c		Crops		variable
d		Department categories	D	variable
	d^s	Stable department categories		classification specific
	d^p	Pasture department categories		classification specific
f		Fertilizer categories	F	variable
	f^m	Manure categories		classification specific
	f^{mp}	Pasture manure categories		classification specific
m		Minerals		{N, P_2O_5, K}
s		Soil type		variable
q		Soil quality class		{high P, medium P, low P, unknown P}
o		Manure storage categories		Variable
δ		derogation		{yes, no}
η		application type		Variable
κ		mineral fraction		{mineral fraction(quick effect, effective fraction (slow effect), resistant fraction (no effect), <not applicable>}
μ		manure aspect type		{slurry,water,ashes,solid}
ω		manure process		variable
ρ		ration factors		Variable
φ		Emission factors		{NH_3}
σ		Source (of manure)		{own, off-farm}
	σ^{own}	own manure		{own}
	$\sigma^{offfarm}$	manure from outside the firm		{off-farm}

In Table 5.2 we provide major subsets as used in the equations as well as the general indices of which they are part. The classifications of a number of indices is straight forward and unchanging such as δ (derogation), and σ (manure source). Other indices are stable such as μ (manure aspect type) where it is possible but unlikely that a different classification will be used. For minerals (m) and emission factors (φ) the elements may change over time as other substances become important, but their definition stays the same. The other indices have classifications that can vary according to the data availability, the requirements at project level, scientific insight, and the classifications used in legislation.

In Table 5.3 we highlight the discrete step indices.

Table 5.3: Discrete step indices

Indices		Description	Alias	Range
q^{milk}		milk quantity class		policy dependent
u		urea content class		policy dependent

Some sets are related to each other, either conceptually or through for instance policy. In the latter case we are dealing with context specific index mappings. Within indices we can have different classifications that can be mapped as well. In Table 5.4 we present these mappings in general terms.

Table 5.4: Index mappings

Indices		Description
Θ		classification mapping
	$\Theta_{f^{FC},f^{DR}}$	mapping of fertilizer classes used in a specific application of MAMBO to the fertilizer classes used by regulatory agency providing calibration data (case of the Netherlands)
Ω		relational mapping (context specific)
	$\Omega_{\delta lh}$	derogation to firm mapping
Φ		relational index mapping (conceptual)
	$\Phi_{\mu f}$	manure aspect type of specific manure categories

There are more index mappings used in the model than presented here. Those index mappings are used primarily for efficiency purposes and for linking the elements in different levels of aggregation.

Table 5.5: Variables in MAMBO

Variables	Description	Units
A	Area	Hectares
B	Secondary production quantity	Kg product
C	Costs	Euro
D	Dummy variable	Binary
E	Emission	Kg emission factor
I	Input quantity	Kg product
M	Quantity of mineral	Kg minerals
N	Numbers	Units
Q	Primary production quantity	Kg product
Π	profit or revenues	Euro

The variables in MAMBO are numerous, but can be captured under eight main groups (Table 5.5). Area (A) refers to cropped area and pastures and is measured in hectares. Secondary production quantity (B) is very important in MAMBO as manure falls under this heading. A variable with the same units is Q (primary production quantity) and includes primary agricultural production, but also the primary products from industrial processes such as manure products. Similarly input quantities have the same unit of measurement and hence manure when used as an agricultural input (organic fertilizer) it changes name and since it becomes specific for the crops and soil types on which it is applied, its indices change as well. In some cases we require dummy variables (D) that take on the binary values of {0,1}. Products can be expressed in terms of their make-up. Obviously mineral content is important in MAMBO analyses and hence we have a variable that captures commodities expressed in terms of their minerals (M). In some cases the mineral quantities change as a result of losses and emissions (E). In the economic modules the physical balances are augmented with financial or monetary balances and hence the need for variables that capture this, namely costs and revenues (C and Π, respectively). Finally we also distinguish variables that hold unit numbers (N), of which the most prominent are livestock numbers.

In Table 5.6 the principal coefficients that are used in MAMBO are highlighted. For further details on origins of these coefficients see Chapter 6.

Table 5.6a: Coefficients in MAMBO general

Coefficients	**Description**	**Defined over conceptual domains**	**Units/dimensions**
α	acceptation degrees	c	dimensionless
ε	Emission coefficient		
ε^{stable}	Stable emission coefficient	m,ρ,ds,f	Kg minerals per kg Manure
$\gamma^{Min\ Effect\ Coef}$	Fixed mineral effect coefficient	m,σ,s,c,f	dimensionless
$\varphi^{min.\ distr.\ fract.}$	Mineral distribution fraction in different components of processing (by) products	m,d,f,D,F,ω	dimensionless
$\varphi^{process\ manure}$	distribution fraction into different processing (by) products components of processed manure	d,f,D,F,ω	dimensionless
μ	Mineral content of fertilizers	m,f	Kg minerals per kg manure
ν	Excretion volume	ρ,a	Kg Manure per animal
$\pi^{manure\ revenue}$	manure revenue: benefits of accepting off-farm manure	f	Euro per kg manure
ρ	Ration factor, proportion of a ration in the overall feed strategy of the animal category	ρ,a	dimensionless
τ	Time fraction, fraction time spend in stables and pastures	ρ,a,d	dimensionless
c^{fixed}	fixed costs related to manure distribution	μ	Euro per kg manure
$c^{application}$	application costs	μ	Euro per kg manure
$c^{storage}$	storage costs	μ	Euro per kg manure
$c^{processing}$	processing costs	ω,f	Euro per kg manure
$c^{transport}$	transportation costs	μ	Euro per kg manure per km
c^{risk}	risk penalty for accepting off-farm manure	s,c,d,f	Euro per kg manure
$e^{min\ application}$	Empirical minimum application of artificial fertilizer	m,c	Kg Minerals per hectare of crop
l^{m}	Legal manure standard	m,δ,s,c	Kg Minerals per hectare of crop
l^{f}	Legal fertilizer standard	m,δ,s,c	Kg Minerals per hectare of crop
l^{l}	fractional allowed deviation from legal fertilization norms		dimensionless
m	Mineralisation/ immobilisation fraction		Dimensionless
d	Distance	r,R	Km

Table 5.6b: Coefficients in MAMBO firm specific

Coefficients	**Description**	**Defined over conceptual domains**	**Units/dimensions**
u	urea content		mg of urea per kg of milk

5.3 Modules

MAMBO is a suite of modules written in GAMS (General algebraic modelling system (McCarl *et al.,* 2012). MAMBO follows a modular approach and allows for calculations at varying levels of aggregation depending on the availability of data and the requirements of a specific application of the model. Each module in the modular structure of MAMBO is a model that does a certain set of calculations, based on input (either external or generated by previous modules) and providing relevant output. Although the modules are all linked through output and input, some modules are more closely linked than others. The criteria we use for separating calculations into modules are the following.

In the first place separation into modules occurs for memory allocation purposes. This is a computational hardware issue. The size of the model with its calculations and internal memory usage should in most cases not exceed the capacity of freely available RAM. MAMBO is based on the assumption that most scenarios should be able to run on a machine with 1 GB RAM, although for some applications 2GB RAM is needed.

Secondly, separation into modules allows the introduction of new components more easily. Changes in legislation guiding firm level decision making invariably requires different calculation methods and procedures. By separating the calculations into modules this can be done in a consistent manner. The starting point of MAMBO is the emulation of the calculation procedures used in MAM with new additions to capture the aspects that could not be handled by MAM such as derogation, soil specific legal manure standards, urea based fertilizer mineral content, to name a few. It allows for alternative procedures envisaged as future developments at the outset to address new requirements from policy and research and/or improve model performance (i.e. calculation speed).

Thirdly calculation times of complicated models such as MAMBO can be quite long. By separating calculations into modules, scenarios that have the same calculation base up to a designated point need not be run over and over again.

MAMBO can be divided into parts with subparts which we initially dubbed model phases. Each of these model phases consists of a number of different modules. The number depends on the settings of the MAMBO application. In Table 5.7a-5.7d the complete structure of the modular approach is presented. The modules make use of common components that ensure the overall consistency. The structure presents the linear process of calculations in the order in which they occur. Initially under MAMBO 1.x we distinguished 7 parts with in total 17 subparts. Under MAMBO 2.x the structure has been reorganized into 6 parts (parts 2 and 3 under MAMBO 1.x have been combined) with 17 subparts containing in total 37 modules

The first part of MAMBO is the preparation of data. Based on user specification specific classifications for indices and data from different sources for different years and specific versions are collected from data repositories and placed in the input directory for the model to use. In the first model phases of the second part of MAMBO manure production is calculated. This is done in three model phases, each of which contains specific modules. The model phases we distinguish are of three different types and this is repeated throughout the framework. The types model phases we distinguish related to calculations are Data change prior to the actual calculations based on user defined settings, often related to scenarios or data variants. The second type of model phase is composed of pre-compilers. Pre-compilers perform certain model processes that are preferably done outside the actual calculations. This consists of data restructuring, internal calculations and performing certain data intensive tasks that are best left outside the main calculations for memory efficiency purposes. The third type of model phase consists of the actual calculations as described further on in this chapter. The fourth type of model phase is related to input data handling and is part and parcel of part I. the fifth type of model phase deals with output data handling and is covered in Part VI where reports for various purposes are prepared.

Table 5.7a: Structure of modular approach (part I and IIa)

Part	**Sub part**	**Module** **Name of GAMS model**	**When used**	**Section where it is described**
I. Data preparation and consistency testing	Data preparation	• FMCCalc • build_RA_P_Diff_dat • Build_Crops_In_P_Diff • Build_Crops_In_P_Diff2MAMBO • Build_Crops_In_P_Diff3MAMBO	Always	
	Data change prior to basic manure production calculations	• AnimalNumbersSA • CropAreaSA • FertilizerMineral ContentSA • FixFertMineral ContentSA • MinimalFertilizer ApplicationSA • UreaContentSA	Scenario specific	6.#
IIa. Manure Production Calculations at firm level and relevant aggregations	Precompilers related to basic manure production calculations	• PreCompiler • PasturePrecompiler • InternalManure Standard	Always	
	Basic manure production calculations	• MAMBOBMPC • MAMBOBMPC2	Always	5.4, 5.5

In table 5.7b we present the aggregation modules of part II of MAMBO denoted by part IIb. In part IIb the model phases are similar in type to the ones described in part IIa (see Table 5.7a). At the end of part IIb data is aggregated from the animal level to the firm level and firm level livestock calculations are done. In addition further aggregation to various levels is done to provide manure production output data.

Table 5.7b: Structure of modular approach (part IIb)

Part	**Sub part**	**Module** **Name of GAMS model**	**When used**	**Section where it is described**
IIb. Aggregation	Data Change prior to aggregate manure production calculations	<none>	Scenario specific	
	Precompilers related to aggregate manure production calculations	<none>	Currently empty	
	Aggregate manure production calculations at firm level	• MAMBOAMPC • MAMBOAMPC2 • MAMBOAMPC3	Always	5.6
	Geographical explicit aggregation of manure production calculations	• MAMBOGMPC	Always	

In Table 5.7c we present the structure of the sections of MAMBO dealing with manure placement of own manure on the firm, and the distribution of surplus manure to areas where there is still potential for manure placement. The firm model in MAMBO version 1.0 was based on the calculation principals used in its predecessor MAM. This implies that quite a bit of preprocessing is necessary to get the data into right format to mimic the MAM calculations while still addressing the issues that could not be addressed in MAM (such as derogation, soil specific manure application norms and firm specific fertilizer mineral contents). In MAMBO 2.x this firm model has been replaced with a mathematical programming model doing the same job much more effectively and efficiently.

The spatial equilibrium model in MAMBO also closely resembles the transport model in MAM which was the only component originally written in GAMS. It was written in GAMS because it entails a linear programming optimization procedure. Again this implies that precompilers are necessary to get the data into the format that can be handled by the model. The transport model has been rewritten in GAMS so that syntax is naming conventions are consistent with MAMBO as a whole. Furthermore small adaptations have been necessary to deal with new issues in legislation.

Table 5.7c: Structure of modular approach (part III-IV)

Part	**Sub part**	**Module** **Name of GAMS model**	**When used**	**Section where it is described**
III. Manure placement on firm	Data change prior to Manure placement on firm	<none>	Scenario specific	
	Precompilers related to manure placement on firm	• RegionalAreaInfo	Always	
	Firm model	• LPBasedFirmModel	Always	5.7
IV. Spatial equilibrium model for distribution of surplus manure	Data change prior to spatial equilibrium model	• ManureExportSA • ManureProcessSA • Acceptation DegreeSA	Scenario specific	
	Precompilers related to spatial equilibrium model	• DataPrepare • CropClassFertClass RequirementCalc	Always	
	Spatial equilibrium model	• Transport model • DR_MineralCalibration	Always Scenario Specific	5.8

In Table 5.7d we see the structure of parts V and VI. Part V deal with the application of organic and inorganic fertilizers and the environmental externalities thereof, namely Ammonia emissions. Part VI is of model phase type output data handling.

Table 5.7d: Structure of modular approach (part V-VI)

Part	**Sub part**	**Module** **Name of GAMS model**	**When used**	**Section where it is described**
V. Application of manure, manure products and artificial fertilizers from various sources	Data change prior to fertilizer application calculations	<none>	Scenario specific	
	Precompilers related to fertilizer application calculations	<none>	Always	
	Fertilizer application calculations	• FAModel • ArtificialFertCalibr	Always	5.9
VI. Reporting results	Report writing	• Report	Always	
	MAMBO STONE conversion tool PREPARATION	STONEplotsB1 STONEplotsB3 STONEplotsB4	Variant specific	
	MAMBO STONE conversion tool	itSTONEMAMBO PDiff2STONEinfo STONEConv TablePolREgST	Variant specific	

5.4 Manure production calculations at animal level

In the first calculation modules of interest in this context, animal numbers are converted into manure quantities by taking into account the housing situation of the animals and whether or not they are grazing. The common housing and grazing circumstances (mathematically expressed as departments with each a certain emission characteristic) are obtained from the annual agriculture census and the Dutch Farm Accountancy Network described in Chapter 6.

The basic outputs we want to generate here are Manure Production per animal category on firm (B^{manure}), Mineral production through manure per animal category on firm (M^{manure}), and the Ammonia emissions that can be attributed to animals and their location (E^{Stable}, $E^{Pasture}$).

This is done in the following manner at the level of animal categories (not individual animals) on establishments of firms located in specific Municipalities (for expositional purposes we will suppress the indices related to level of aggregation). The manure production depends on the number of animals ($N^{animals}$), the ration (ρ) the animals are fed, the excretion volume (ν) of the animal and the time spent in various departments (stable and pasture) in which the animal is located. Rations are independent of whether an animal is housed indoors or outdoors. The department is in general an animal housing structure (interchangeably called stable throughout this chapter). Time fraction (τ) is used to assign more than one department (pasture in summer and stable in winter) to animals during a year, where relevant. The dimension is kg manure per animal category per department per farm establishment.

$$B_{\rho da}^{manure} = N_{da}^{animals} * \rho_{\rho a} * \nu_{\rho a} * \tau_{\rho da} \tag{1}$$

Within MAMBO, manure categories are defined in terms of the animals that produce the manure, the departments where the manure is produced, and the type of rations that the animals are fed.

$$B_{\rho daf}^{manure} \Leftrightarrow B_{\rho da}^{manure} \tag{2}$$

Mineral production (M^{animal}) of an animal in a department for a manure category depends on the mineral content of the manure excreted (μ). The dimension is kg mineral in manure per animal category per department (hence per mineral category) per farm. There is a further difference in definition of the mineral content. The scientific manure mineral content is the content prior to emissions, while the fixed manure mineral content is net of emissions.

$$M_{mdaf}^{manure} = \sum_{\rho} \left(B_{\rho daf}^{manure} \right) * \mu_{mf} \tag{3}$$

The mineral content of manure warrants a little extra explanation. In principle depending on the specific circumstances on the farm the mineral content of manure will differ. In MAMBO certain standardized procedures are used. This is the basis of the multiple mineral accounting framework used in the modelling procedures. The procedures are mentioned here in random order. In the first place we have the legal mineral content of manure (this is a relevant concept in Dutch agriculture). These are the mineral contents used for evaluating if firms comply with the manuring standards for the cropped area. In the second place MAMBO also uses the best scientific knowledge concerning mineral content of manure in order to provide as accurate calculations as possible concerning emissions of minerals into the environment. In the third place for the specific case of dairy cattle (in the Dutch case), there is an alternative method for determining mineral contents of manure based on milk urea content and average milk production per cow. This milk urea procedure is valid only for the legal mineral accounting framework and not for the scientific accounting framework. In the current version of MAMBO, manure mineral contents related to milk urea and milk production are discrete amounts based on tables. The alternative approach is the use of the underlying equations that specify the relationship. Equation 3 therefore can be rewritten:

$$M_{mda^{nd}f}^{manure,fixed} = \sum_{\rho} \left(B_{\rho da^{nd}f}^{manure} \right) * \mu_{mf}^{fixed} \tag{3a}$$

$$M_{m^{N}da^{d}f}^{manure,urea-based} = \sum_{\rho} \left(B_{\rho da^{d}f}^{manure} \right) * \sum_{uq^{milk}} \left(\mu_{m^{N}uq^{milk}}^{milk\ urea-based} * D_{u} * D_{q^{milk}} \right) \tag{3b}$$

$$M_{mdaf}^{manure,scientific} = \sum_{\rho} \left(B_{\rho daf}^{manure} \right) * \mu_{mf} \tag{3c}$$

As of 2010-2011 a new methodology for the calculation of ammonia emissions is available based on total ammonia nitrogen (TAN) for this purpose the scientific manure based mineral production is separated into mineral fractions.

$$M_{m\kappa daf}^{manure,TAN} = \sum_{\rho} \left(B_{\rho daf}^{manure} \right) * \mu_{m\kappa f} \tag{3d}$$

$$D_{u}^{lb} < u^{milk} < D_{u}^{ub} \tag{4}$$

$$D_{q^{milk}}^{lb} < Q^{milk} < D_{q^{milk}}^{ub} \tag{5}$$

As part of the TAN methodology The possibility of mineralisation and immobilisation of nitrogen has been introduced in MAMBO:

$$M_{m\kappa daf}^{manure} = \sum_{\kappa^{*}} \left(M_{m\kappa^{*}daf}^{manure} \right) * m_{m\kappa^{*}\kappa f} \tag{6}$$

where:

$$\sum_{\kappa} \left(M_{m\kappa daf}^{manure} \right) = \sum_{\kappa^{*}} \left(M_{m\kappa^{*}daf}^{manure} \right) \tag{7}$$

Due to:

$$\sum_{\kappa} \left(m_{m\kappa^{*}\kappa f} \right) = 1 \tag{8}$$

Mineralisation is currently only implemented at stable and storage level and used at stable level only:

$$M_{m\kappa daf}^{manure} = \sum_{\kappa^{*}} \left(M_{m\kappa^{*}daf}^{manure} \right) * m_{m\kappa^{*}\kappa f}^{stable} \tag{6a}$$

In specific circumstances alternative standards can be used depending on the requirements of a specific application of MAMBO.

The emission factors (NH3, NO, N2, N2O in the case of nitrogen and ammonia monitoring in the Netherlands) for grazing ($\varepsilon^{pasture}$) is different from that of the animal housing (ε^{stable}). Hence, the mineral emissions (E) from the animal manure inside the animal house and from grazing are expressed separately in equations 9 and 10 for the non-TAN methodology used prior to 2011 and equations 9a and 10a for the methodology based on TAN. The emission is expressed as kg mineral emitted per animal category per department (hence per mineral category) per farm and emission kind (one of them is ammonia).

$$E^{stable}_{\varphi m d^s af} = M^{manure,scientific}_{md^s af} * \varepsilon^{stable}_{\varphi m d^s f} \qquad \text{(9, flag 1 in Figure 4.1)}$$

$$E^{pasture}_{\varphi m d^p af} = M^{manure,scientific}_{md^p af} * \varepsilon^{pasture}_{\varphi m d^p f} \qquad \text{(10, flag 2 in Figure 4.1)}$$

$$E^{stable}_{\varphi m \kappa d^s af} = M^{manure,scientific}_{m\kappa d^s af} * \varepsilon^{stable}_{\varphi m\kappa d^s f} \qquad \text{(9a, flag 1 in Figure 4.1)}$$

$$E^{pasture}_{\varphi m \kappa d^p af} = M^{manure,scientific}_{m\kappa d^p af} * \varepsilon^{pasture}_{\varphi m\kappa d^p f} \qquad \text{(10a, flag 2 in Figure 4.1)}$$

The mineral production per animal after stable and pasture emission is calculated by adding up the two emission sources. The mineral production (*M*) after emissions of minerals at animal level is given in equation 11.

$$M^{manure,scientific,after\,emissions}_{mdaf} = M^{manure,scientific}_{mdaf} - \sum_{\varphi}\left(E^{pasture}_{\varphi mdaf} + E^{stable}_{\varphi mdaf}\right) \qquad (11)$$

With TAN this becomes:

$$M^{manure,scientific,after\,emissions}_{m\kappa daf} = M^{manure,scientific}_{m\kappa daf} - \sum_{\varphi}\left(E^{pasture}_{\varphi m\kappa daf} + E^{stable}_{\varphi m\kappa daf}\right) \qquad \text{(11a)}$$

5.5 Emissions at firm level

Emissions from manure storage at farm level are calculated at the level of stables in the Aggregate Manure Production Calculations module. The rationale is that storage systems are often linked to stable categories. However there is often more than one storage system available per stable type. Information on the storage distribution is used to distinguish what storage systems are applicable on average for each firm (see equation 12 for non-TAN methodology and 12a for TAN methodology). Prior to these emissions it is possible that through immobilisation or mineralisation mineral contents of manure in terms of mineral fractions has changed (see equation 6b).

$$M^{manure,scientific,after\,emissions}_{m\kappa daf} = \sum_{\kappa^*}\left(M^{manure,scientific,after\,emissions}_{m\kappa^* daf}\right) * m^{storage}_{m\kappa^*\kappa f} \qquad \text{(6b)}$$

$$E^{storage}_{mdfo} = s_{do} * \varepsilon^{storage}_{\varphi mdo} * \sum_{a} M^{manure,scientific,after\,emissions}_{mdaf} \qquad \text{(12, flag 4 in Figure 4.1)}$$

$$E^{storage}_{mdfo} = s_{do} * \varepsilon^{storage}_{\varphi m\kappa do} * \sum_{a} M^{manure,scientific,after\,emissions}_{m\kappa daf} \qquad \text{(12a, flag 4 in Figure 4.1)}$$

Surplus manure can be processed on farm prior to transportation. Although on-farm processing is not yet implemented in MAMBO the principal is highlighted anyway.

As presented in equation 13, the emissions from processing depend on the amount of manure processed, the mineral content of that manure and the way of processing. Manure processing at firm level is currently not implemented in MAMBO because it is only a minor source of emissions. With the growing importance of manure processing, also at fram level extensions are foreseen in the near future.

$$E^{process}_{\varphi\to\phi,M\varepsilon} = \varepsilon^{process}_{\varphi\to\phi,M\varepsilon} * \sum_{Rrm}\left(\mu_{M\varphi} * \sum_{FE}\left(Q^{process}_{FERrm,\varphi}\right) * R^{average}_{Rrm,\varphi,M}\right) \qquad \text{(13, flag 5 in Figure 4.1)}$$

5.6 Application of own manure

Firms with both animals and crops and or pastures will apply their manure to their own fields to the extent legislation permits.

Farm firms with pastures and crops are faced with legal standards regarding the amounts of minerals from manure and other fertilizers they can apply on their land. With respect to own manure applied to crops, firms have to take into account the maximum amount of minerals from manure that may be applied to crops. This amount depends on the legal manure standard that is defined for different crops and whether or not the firm is eligible for derogation. In addition in 2006 in the Netherlands, government provided firms with the possibility of applying an additional 5% manure to ease the overheated manure market, by not fining the first 5% excess manure placement over and beyond what is permitted by law. This extra allowance ($l^{allowance}$) can take on the value zero if such an allowance is not in place in a specific year. This is summarized in equation 14a.

Furthermore the maximum allowable manure deposition can also be limited by another set of legislation covering all minerals from all fertilizer sources. Here we deal with legal fertilizer standard (l) which is soil specific and can be at any level of aggregation. We also need to take into account the fact that there are certain minimum levels of artificial fertilizer applications based on information from manuring experts. The degree to which the minerals count towards the maximum application constraint depends on the minimum effect coefficient. This coefficient is 1 for phosphate but unequal to 1 for nitrogen from manure (organic fertilizer). The value of this coefficient depends on where the manure comes from (own farm or from outside the farm), soil type, crop, and fertilizer or manure category ($\gamma^{Min\ effect\ coef}$), which is also regionally specific. This is summarized in equation 15a.

$$M_m^{Max\,allowable,crops} \leq \sum_{sc}\left(\sum_{\delta}\left(D_{\delta}^{derogation} * l_{m\delta c}^{m}\right) * A_{sc}^{crops} * \left(1 + l^{allowance}\right)\right) \tag{14a}$$

$$M_{mf}^{Max\,allowable,crops} \leq \sum_{sc}\left(\sum_{\delta\sigma^{own}}\left(D_{\delta}^{derogation} * \left[\frac{\left(l_{m\delta sc|r}^{f} - e_{mc}^{Min\,application}\right)}{\gamma_{m\sigma^{own}scf|n}^{Min\,effect\,coef}}\right]\right) * A_{sc}^{crops} * \left(1 + l^{allowance}\right)\right) \tag{15a}$$

The actual amount of minerals from manure applied on crops depends on fertilizer categories that capture feeding strategies pursued by the farmers. The amount of minerals the firm has to take into account are based on the fixed mineral contents (equation 16a)[3].

$$M_m^{Actual,crops} = \sum_{ad^s f}\left(M_{md^s af}^{manure,fixed}\right) \tag{16a}$$

Alternatively it can be calculated over the scientific knowledge-based mineral production of stable manure (equation 16b)[4].

$$M_m^{Actual,crops} = \sum_{ad^s f}\left(M_{md^s af}^{manure,scientific}\right) \tag{16b}$$

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[3] In the current situation (*post* 2005 legislation) the amount of minerals the firm has to take into account are based on the legally fixed mineral contents after emissions

[4] This was the case up till 2005 where scientifically based firm level mineral accounts were used to determine allowable application.

The farm household is faced with an optimization problem, what manure to apply to which crops in order to minimize the surplus manure that has to be disposed of. Trading manure is costly. Farmers are faced with transaction costs related to finding a destination for their manure, transportation costs for getting the manure to the destination. This firm can be another farmer with more crop area than own manure or a manure processing plant[5]. We first describe the optimization procedure predominantly used until 2011. Later we describe a new procedure implemented with the advent of manure standards based on soil phosphate content, which made the first procedure unworkable.

The minimization problem faced by the farmer is twofold. In the first place the farmer will minimize the surplus manure. If there is no surplus manure, the farmer will optimize manure application by directing the manure to those crops that are best served with manure from an agronomic perspective.

$$\min B_{daf}^{manure,surplus} = B_{daf}^{manure} - B_{daf}^{manure,applied\ own\ farm} \tag{17}$$

In order to abide by the constraint presented in equation 15a and 15b the following equation can be derived:

$$\sum_{\delta}\left(D_{\delta}^{derogation} * l_{m\delta c}^{m}\right) * A_{scdf}^{crops\ with\ own\ manure} * \left(1 + l^{allowance}\right) \geq I_{dfsc}^{own\ manure,applied\ own\ crops} * \left[\frac{\sum_{a} M_{mdaf}^{manure,fixed}}{\sum_{a} B_{daf}^{manure}}\right] \tag{18}$$

where

$$\sum_{sc} I_{dfsc}^{own\ manure,applied\ own\ crops} = \sum_{a} B_{daf}^{manure,applied\ own\ farm} \tag{19}$$

This equation is defined over the domains of minerals, soil type, crops, department category and fertilizer category. The two choice variables involved are cropped areas with own manure and manure volume applied to crops. These choice variables are defined over the four domains of the equation: soil type, crops, department category and fertilizer category.

In a similar way we derive an equation to capture the constraint related to the legal fertilizer standards:

$$\sum_{\delta\sigma^{own}}\left(D_{\delta}^{derogation} * \left[\frac{\left(l_{m\delta sc|r}^{f} - e_{mc}^{Min\ application}\right)}{\gamma_{m\sigma^{own}scf|n}^{Min\ effect\ coef}}\right]\right) * A_{scdf}^{crops\ with\ own\ manure} * \left(1 + l^{allowance}\right) \geq B_{dfsc}^{own\ manure,applied\ own\ crops} * \left[\frac{\sum_{a} M_{mdaf}^{manure,fixed}}{\sum_{a} B_{daf}^{manure}}\right] \tag{20}$$

We also define a manure volume balance (equation 22) and a cropped area balance (equation 21):

$$A_{sc}^{crops} \geq \sum_{df}\left(A_{scdf}^{crops\ with\ own\ manure}\right) \tag{21}$$

---

[5] In the Netherlands farmers with surplus manure currently pay to have the manure removed in terms payments to the firm at the destination. In other countries and in the Netherlands in the past farmers have to pay to get manure if they do not have sufficient amounts. In both cases trading is costly and include the opportunity costs of not applying the manure on the own farm.

$$\sum_{a} B_{d^{p}af}^{manure} = \sum_{sc} \left(B_{d^{p}fsc}^{own\,manure,applied\,own\,pastures} \right) \tag{22a}$$

$$\sum_{a} B_{d^{s}af}^{manure} \geq \sum_{sc} \left(B_{d^{s}fsc}^{own\,manure,applied\,own\,crops} \right) \tag{22b}$$

Note the difference between pasture and stable manure. Pasture manure is manure deposited by grazing animals on pastures during grazing and constitutes a volume that cannot enter into the surplus of the farm, while for stable manure this surplus can exist. Because we have used a time fraction correction module (presented in Figure 5.2), equation 22a will never be infeasible. Certain crop fertilizer combinations are not allowed and non-negativity constraints are abided by.

The second optimization is a stepwise process for those cases where:

$$B_{daf}^{manure,surplus} = 0 \tag{23}$$

and

$$A_{sc}^{crops} - \sum_{df} \left(A_{scdf}^{crops\,with\,own\,manure} \right) \neq 0 \tag{24}$$

The objective function becomes:

$$\max A_{scdf}^{crops\,with\,own\,manure} \tag{25}$$

for the crop with first preference for manure, given constraint equations 18-22, and abiding by non-negativity constraints and rules regarding allowed crop fertilizer combinations. If equation 23 holds we repeat the process for the crop with second preference for manure holding $B_{daf}^{manure,applied\,own\,farm}$ for the crop with first preference fixed at the optimal level. We repeat the process until all manure has been applied to crops and are held fixed. This implies that there are no degrees of freedom left and optimization is complete.

In the implementation of this optimization MAMBO follows the logic of the application rules that have been used in the past in order to ensure that there is consistency between the results over time. This implies that there are a few important side constraints that play a role. In the first place, the most limiting mineral is used to determine the amount of manure that can be placed on a plot (implicit section of a field). This implies that when firms have more than one type of manure with varying nitrogen/phosphate ratios the calculated optimum is not necessarily the global optimum without this constraint.

The new procedure implemented with the advent of manure standards based on soil phosphate contents links up with a general tendency in agricultural policy both at national and EU level to make regulations much more firm specific.

To begin we need a new equation for the manure and fertilizer standards regarding phosphate:

$$M_{m}^{Max\,allowable,crops} \leq \sum_{scq} \left(\sum_{\delta} \left(D_{\delta}^{derogation} * l_{m\delta cq}^{m} \right) * A_{scq}^{crops} * \left(1 + l^{allowance} \right) \right) \tag{14b}$$

Where the standard is dependent on the soil quality class. We also have a new definition for cropping area:

$$A_{scdf}^{crops\ with\ own\ manure} = \sum_{q} \left(A_{sqcdf}^{crops\ with\ own\ manure} \right) \quad (21a)$$

The optimization problem is a mathematical programming problem where there is a simultaneous solution generation for all issues given all constraints. The issues are three-fold in descending order of importance:

1. Minimization of the costs of disposal of excess manure;
2. Optimization of the choice of crops to be fertilized with own farm animal manure;
3. Information costs.

The cost of disposal of excess manure is based on the same principles as the model described before. The main difference is that there is a single objective function and the calculations use mathematical programming techniques.

The new objective function is:

$$\min C = \omega^{disposal} \sum_f C_f^{disposal} + \omega^{crop\ penalty} \sum_{sqc} C_{sqc}^{crop\ penalty} + \omega^{information} \sum_{mksqcdf} M_{m\kappa sqcdf}^{potential} \quad (26)$$

Where the costs of disposal are defined as the fraction not applied to crops of the manure available times the costs for manure disposal. These costs consists of transportation costs and the price paid to the iuser of the disposed manure, be it an arable cropping farm or a manure processing facility.

$$C_f^{disposal} = \sum_{dsqc} \left(\left(1 - f_{dfsqc} \right) * \sum_{\rho a} \left(B_{\rho daf}^{manure} \right) \right) \times p_f^{manure\ disposal} \quad (27)$$

The penalty for fertilizing crops with manure is consistent with the second part of the earlier optimization procedure described above.

$$C_{sqc}^{crop\ penalty} = \sum_{df} f_{dfsqc} * \sum_{\rho a} \left(A_{sqcdf}^{crops\ with\ own\ manure} \right) \times p_c^{manure\ penalty} \quad (28)$$

The information costs allow the model to determine the remaining fertilization potential for each standard.

This objective function is subject to a number of constraints.

Application levels of manure may not exceed the standards provided by environmental regulations. Hence the following equations must hold 14a (nitrogen in manure) 14b (phosphate) , 15a (for nitrogen available for crop growth) in addition we add an equation to limit fertilizer use to below toxic levels (see equation 29). This equation is redundant in the current situation where the environmental regulations are limiting for all minerals under scrutiny.

$$M_{mscq}^{Max\ allowable,crops} \leq A_{scq}^{crops} * t_{sc}^{croptoxicitylevel} \quad (29)$$

Finally balance equations are needed. Besides 22a and 22b and 21 and 21a the fraction of manure applied to different crop-soil combinations may not exceed 1.

5.7 Distribution of surplus manure using a spatial equilibrium model

General

After the manure has been placed on the own firm to the extent that rules and regulations allow, some firms are confronted with surplus manure they need to dispose of. Some firms with little or no livestock will still have fields that can be manured. The surplus manure distribution module of MAMBO has been developed with the explicit purpose of determining the spatial equilibrium in the manure market. The calculations in MAMBO version 1.0 closely follow the logic developed in MAM (Groenwold *et al.*, 2002).

It is important to note an important difference between the calculations at this level and the calculations with respect to the optimal allocation of own manure on own fields. In the previous calculations it was the fixed manure mineral content as described in legislation in combination with the legal norms with respect to manure and fertilizer application that determined the equilibrium. In the following equations it is the actual mineral content that is important. The constant factor between these different modes of calculation or accounts is the volume of manure. The volume of manure is based on best scientific knowledge and each manure type has its own mineral content. In some cases as we argued earlier mineral content can be firm specific as in the case of dairy cattle where manure mineral contents are calculated based on milk urea content and average milk production per cow.

A second important difference is that the scale at which we calculate the spatial equilibrium is different. In the previous sections the scale was the firm and everything on it. Now the scale is a regional area. These regional areas are the manure regions defined at the national level and used in spatial disaggregation of policy instruments. These manure regions represent areas with different types of livestock management systems (see Chapter 7 for a map of these regions).

Surplus manure that cannot be applied on own fields can be disposed of in several ways. It can be transported to other firms, exported from the agricultural sector, processed or stored. In the case of storage one should also take into consideration the amount of manure in store from the previous period.

$$B_{df|r}^{manure,surplus} + B_{df|r,t-1}^{Storage} = \sum_{R} B_{df|r\to R}^{manure,transported} + \sum_{\omega} B_{df\omega|r}^{manure,processed} + B_{df|r}^{manure,Exported} + B_{df|r}^{Storage} \qquad (30)$$

where the total amount of exported manure and processed manure are limited by demand constraints that are given exogenously. Whether or not storage is taken into account is a matter of user defined choice.

The processed manure has its own dynamics. Processed manure is processed in manure products based on fractions that the of the manure that go into each of the (by)products. One of these by-products is wastewater from dehydration processes which contains insignificant amounts of minerals and can be dumped on the surface water. As with the case of unprocessed manure there are exogenous demand constraints related to export.

$$\sum_{\omega}\left(\varphi_{dfDF\omega}^{proceesed\ manure\ fraction} * B_{df\omega|r}^{manure,processed}\right) = QB_{DF|r}^{manure\ product,Exported} + B_{DF|r}^{manure\ product,Dumped} + \sum_{R} Q_{DF|r\to R}^{manure\ product,Transported} \qquad (31$$

The transported manure and manure products can be applied to fields of farmers willing to accept the manure and/or products. Acceptation of manure depends on the potential application area comparable to what happened to own manure applied to own fields, which depends on legislation and an acceptation degree factor (α_c) which is crop and regional area specific. The acceptation degree factor depends on perceived risk of using off-farm manure and is based on empirical information from the Dutch Farm Accountancy Network. Note that normally the acceptation degree factor is less or equal to 1 if farmers are to abide by the rules and regulation. However the fact that we use most limiting minerals to define allocation according to the existing methodology, some farmers will have additional space left for application within the bounds of the law. This can lead to acceptation degrees in excess of 1.

$$\sum_{\delta\sigma^{offfarm}} \left(\left[\frac{\left(l^{f}_{m\delta sc|R} - e^{Min\,application}_{mc} \right)}{\gamma^{Min\,effect\,coef}_{m\sigma^{offfarm}scf|N}} \right] \right) * \left(D^{derogation}_{\delta} * \left[A^{crops}_{\delta sc|R} - \sum_{DF} A^{crops\,with\,own\,manure}_{scDF|R} \right] \right) * \left(1 + l^{allowance}\right) * (\alpha_{c|R}) \geq$$

$$Q^{manure\,product,transported}_{df|r \to R} * \left[\frac{M^{manure\,product,scientific}_{mdf|r}}{\left(Q^{manure\,product,Exported}_{df|r} + Q^{manure\,product,Dumped}_{df|r} + Q^{manure\,product,Transported}_{df|r \to R} \right)} \right] + B^{manure,transported}_{df|r \to R} * \left[\frac{\sum_{a} M^{manure,scientific}_{mdaf|r}}{\sum_{a} B^{manure}_{daf|r}} \right] \qquad (32)$$

Where the mineral content of manure products is defined as follows:

$$M^{manure\,product,scientific}_{mdf|r} = \sum_{DF\omega} \varphi^{Mineral\,distribution\,fraction}_{mDFdf\omega} * B^{manure,processed}_{DF\omega|r} * \frac{\sum_{a} M^{manure,scientific}_{mDaF|r}}{\sum_{a} B^{manure}_{DaF|r}} \qquad (33)$$

The left-hand side of equation 32 signifies potential demand. The right-hand side is supply. In equilibrium there is a quantity of manure and manure products that are applied to crops on soils . In order to determine how the surplus manure is distributed we apply a spatial equilibrium model based on linear programming techniques. In order to determine the optimal allocation minimization of distribution costs is used as main concept. Distribution costs entail all costs necessary to dispose of surplus manure and encompass physical distribution costs (loading and unloading manure, storage and transport), manure processing costs and export costs..

The objective function becomes:

$$\min C^{AggregateCost} - \Pi^{Aggregate\,revenues} \qquad (34)$$

Where $C^{Aggregate\ Cost}$ are the aggregate costs, and $\Pi^{Aggregate\ revenue}$ are aggregate revenues from manure distribution:

$$C^{Aggregate\,Costs} = \sum_{df} \left(\begin{array}{l} \sum_{r\rightarrow R|r=R} \left(\sum_{\mu\in M\mu f} \left(\begin{array}{l} \left(c_{\mu}^{fixed,in\,r} + c_{\mu}^{storage,in\,r} + \sum_{\sigma^{offfarm}} c_{\sigma^{offfarm}f}^{application} \right) * \\ \left(B_{df|r\rightarrow R}^{manure,transported} + Q_{df|r\rightarrow R}^{manure\,product,transported} \right) \end{array} \right) \right) + \\ \sum_{r\rightarrow R|r\neq R} \left(\sum_{\mu\in M\mu f} \left(\begin{array}{l} \left(\begin{array}{l} c_{\mu}^{transport} * d_{r\rightarrow R} + \\ c_{\mu}^{fixed,out\,r} + c_{\mu}^{storage,out\,r} + \sum_{\sigma^{offfarm}} c_{\sigma^{offfarm}f}^{application} \end{array} \right) * \\ \left(B_{df|r\rightarrow R}^{manure,transported} + Q_{df|r\rightarrow R}^{manure\,product,transported} \right) \end{array} \right) \right) + \\ \sum_{\omega|r} \left(\begin{array}{l} \left(\sum_{\mu\in M\mu f} \left(c_{\mu}^{storage,\,processed\,manure} + c_{\mu}^{fixed,Sector} \right) + c_{\omega f}^{process} \right) * \\ B_{df\omega|r}^{manure,\,processed} \end{array} \right) \\ \sum_{r} \left(\sum_{\mu\in M\mu f} \left(\begin{array}{l} c_{\mu}^{fixed,Export} * \\ \left(B_{df|r}^{manure,Exported} + Q_{df|r}^{manure\,product,Exported} \right) \end{array} \right) \right) + \\ \sum_{sc} \left(c_{scdf}^{risk\,penalty} * I_{scdf|R}^{crops\,with\,offfarm\,manure} \right) \end{array} \right) \tag{35}$$

and

$$\Pi^{Aggregate\,revenues} = \sum_{r\rightarrow R,r=R} \left(\pi_{fR}^{manure\,revenue} \left[B_{df|r\rightarrow R}^{manure,transported} + Q_{df|r\rightarrow R}^{manure\,product,transported} \right] \right) \tag{36}$$

For surplus manure in a specific region the following possibilities exist:
1. Supply within the region;
2. Supply to other regions;
3. Export.

Activities related to manure distribution

The following activities are related to manure distribution:
1. Loading and unloading manure and processed manure products;
2. Transport and storage of manure and processed manure products;
3. Application of manure and processed manure products;
4. Processing of manure;
5. Export of manure and processed manure products.

These activities can be presented graphically (Figure 5.1):

In case there is manure processing there will be more handling costs due to loading and unloading than when manure is transported to fields of farmers with excess area for manuring.

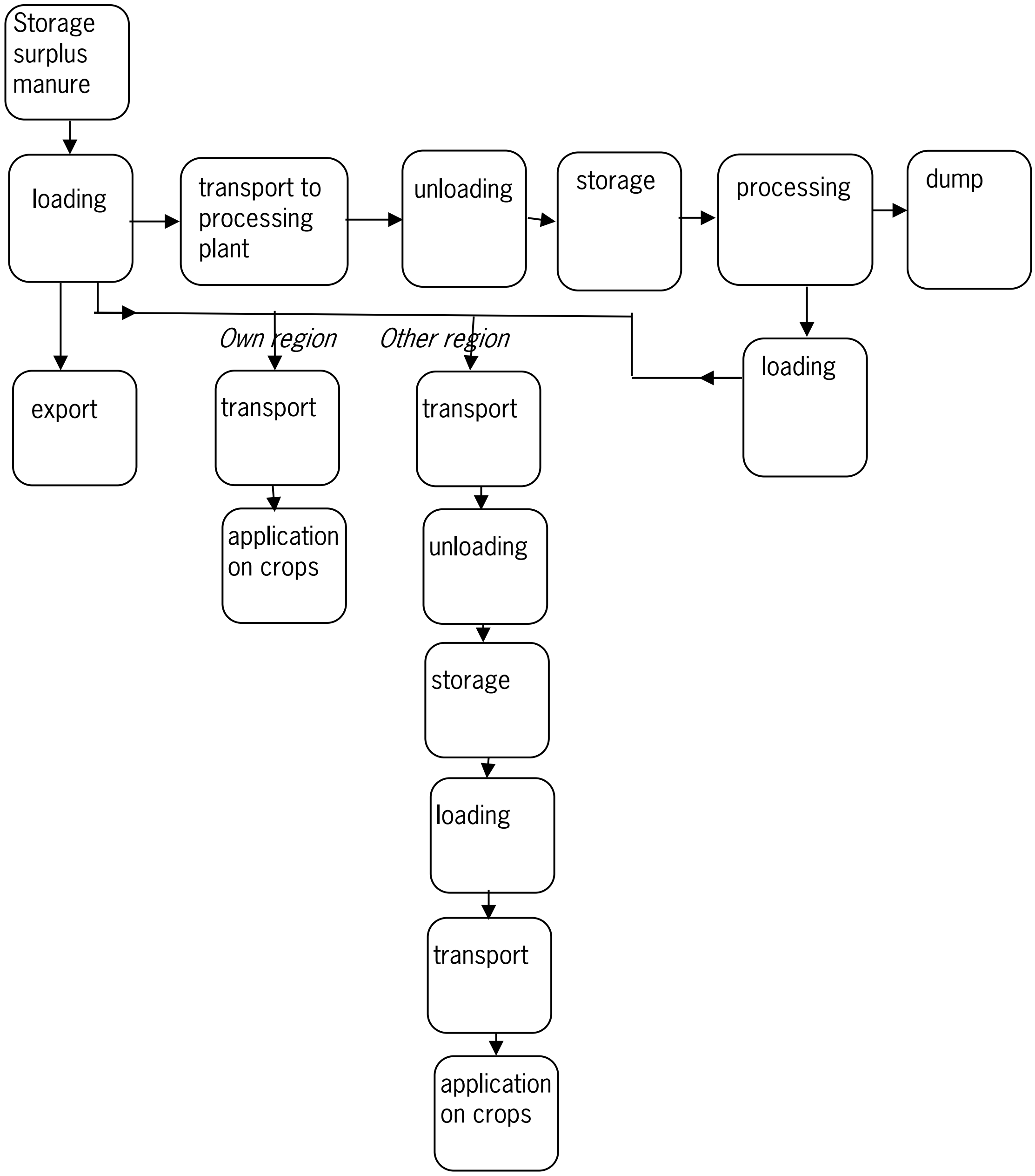

Figure 5.1: Manure Transport Activities

Transportation costs

Transportation costs contain a fixed component dependent on manure aspect type and destination (within the regional area, outside the regional area or export). Transportation costs between regional areas also depend on the distance traveled.

Transport costs in terms of minerals between different types of manure vary because the level of the costs depends on the volume transported. Therefore manure categories with low mineral content will generally be transported over shorter distances. High volume manure tends to be distributed within the own region or nearby deficit regional areas.

5.8 Application of organic and inorganic fertilizers and related emissions

In Sections 5.6 and 5.7 we discussed the calculations that provide us with the amounts of manure allocated for application on crops and pastures. In this section these results are combined and the Emissions related to fertilizer application are calculated. In addition additional fertilization with inorganic fertilizers is also simulated.

We can calculate the area available for fertilization with inorganic fertilizers based on the initial area and subtracting the areas with full fertilization based on placement of own manure (from Section 5.6) and placement of off-farm manure and manure products (from Section 5.7).

$$A_{\delta sc|m}^{crops,not\ fertilized} = A_{\delta sc|m}^{crops} - \sum_{df}\left(A_{scdf|m}^{crops\ with\ own\ manure} + A_{scdf|m}^{crops\ with\ offfarm\ manure} + A_{scdf|m}^{crops\ with\ manure\ products}\right) \tag{37}$$

$$\sum_{\delta\sigma^{offfarm}}\left(\left[\frac{\left(l_{m\delta sc|R}^{f}\right)}{\gamma_{m\sigma^{offfarm}scf|m}^{Min\ effect\ coef}}\right]\right) * \left(\left[A_{\delta sc|m}^{crops,not\ fertilized}\right]\right) * \left(1 + l^{allowance}\right) \geq I_{\delta fsc|m}^{artificial\ fertilizer} * \mu_{mf} \tag{38}$$

with

$$e_{mc}^{Min\ application} \leq \frac{\sum_{f\in m}\left(I_{\delta fsc|m}^{artificial\ fertilizer} * \mu_{mf}\right)}{\sum_{f\in m}\left(A_{\delta fsc|m}^{artificial\ fertilizer}\right)} \tag{39}$$

Holding for each soil type with crops. We now have all the organic and inorganic fertilizer applications and can calculate application emissions:

$$\begin{aligned} E_{\varphi mscf|s}^{Organic\ application} = &\left(\sum_{\kappa\delta\sigma\eta\mu}\left(\begin{matrix} M_{m\delta\sigma fsc}^{Organic\ Minerals\ applied\ to\ crops} * \eta_{\eta\mu sc}^{application\ utilization} * \\ \varepsilon_{\varphi m\kappa\eta\mu}^{application} * \varphi_{m\kappa f}^{Mineral\ fraction} \end{matrix}\right)\right) \\ &* \gamma_{mcf|s}^{Mineral\ effect} * \varphi_{sc|s}^{season\ application} \qquad \mu \in \Phi_{\mu f}, f \in \{f^{m}, f^{mp}\} \end{aligned} \tag{40, flag 6 in Figure 4.1}$$

For artificial (inorganic) fertilizers a different equation is used

$$E_{mscf^{a}|s}^{Inorganic\ application} = I_{\delta scf^{a}}^{Artificial\ fertilizer} * \mu_{mf^{a}} * \varepsilon_{mf^{a}}^{Artificial\ fertilizer} \tag{41, flag 6 in Figure 4.1}$$

5.9 Time fraction correction

One of the coefficients in Section 5.4 is the time fraction $\tau_{\rho da}$ (see equation 1). This time fraction is based on exogenous information and not at present on specific farm level information of each farm. Hence there is a possible discrepancy between the time fraction spend on pastures by grazing animals and the available grazing areas of the firm. Hence MAMBO uses a time fraction correction procedure for firms with grazing animals. This component need only be invoked if the data on animal housing and grazing time in incomplete at firm level.

Farm firms with pastures and crops are faced with legal standards regarding the amounts of minerals from manure and other fertilizers they can apply on their land. With respect to manure deposited on pastures in the process of grazing, firms have to take into account the maximum amount of minerals from manure that may be deposited on pastures. This amount depends on the legal manure standard that is defined for different crops and whether or not the firm is eligible for derogation. In addition in 2006, government provided firms with the possibility of applying an additional 5% manure to ease the overheated manure market, by not fining the first 5% excess manure placement over and beyond what is permitted by law. This extra allowance ($l^{allowance}$) can take on the value zero if such an allowance is not in place in a specific year. This is summarized in equation 14c.

$$M_{m}^{Max\,allowable,pastures} \leq \sum_{sc^p}\left(\sum_{\delta}\left(D_{\delta}^{derogation} * l_{m\delta c^p}^{m}\right) * A_{sc^p}^{pastures} * \left(1 + l^{allowance}\right)\right) \tag{14c}$$

Furthermore the maximum allowable manure deposition can also be limited by another set of legislation covering all minerals from all fertilizer sources. Here we deal with legal fertilizer standard (l^f) which is soil specific and can be at any level of aggregation. We also need to take into account the fact that there are certain minimum levels of artificial fertilizer applications based on information from manuring experts. The degree to which the minerals count towards the maximum application constraint depends on the minimum effect coefficient. This coefficient is 1 for phosphate but unequal to 1 for nitrogen from manure (organic fertilizer). The value of this coefficient depends on where the manure comes from (own farm or from outside the farm), soil type, crop, and fertilizer or manure category ($\gamma^{Min\ effect\ coef}$), which is also regionally specific. This is summarized in equation 15b.

$$M_{mf}^{Max\,allowable,pastures} \leq \sum_{sc^p}\left(\sum_{\delta\sigma^{own}}\left(D_{\delta}^{derogation} * \left[\frac{\left(l_{m\delta sc^p|r}^{f} - e_{mc^p}^{Min\,application}\right)}{\gamma_{m\sigma^{own}sc^p f|n}^{Min\,effect\,coef}}\right]\right) * A_{sc^p}^{pastures} * \left(1 + l^{allowance}\right)\right) \tag{15b}$$

The actual amount of minerals deposited on pastures by grazing animals depends on the time spent grazing (the feed rations are defined by the fact that the animals graze). Following the discussion on fertilization standards and multiple accounting we can distinguish fixed actual mineral amounts (equation 16c[6].

$$M_{m}^{Actual,pasture,fixed} = \sum_{a^g d^p f}\left(M_{md^p a^g f}^{manure,fixed}\right) \tag{16c}$$

Alternatively it can be calculated over the scientific knowledge-based mineral production of grazing animals on pastures (equation 16d)[7].

$$M_{m}^{Actual,pasture,scientific} = \sum_{a^g d^p f}\left(M_{md^p a^g f}^{manure,scientific}\right) \tag{16d}$$

If the actual amount of deposited minerals on pastures exceeds the maximum allowable deposition, the time fraction needs to be revised. Note that the maximum allowed mineral application depends on the type of manure.

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[6] In the current situation in the Netherlands (*post* 2005 legislation) the amount of minerals the firm has to take into account are based on the legally fixed mineral contents after emissions

[7] This was the case up till 2005 in the Netherlands, where scientifically based firm level mineral accounts were used to determine allowable application.

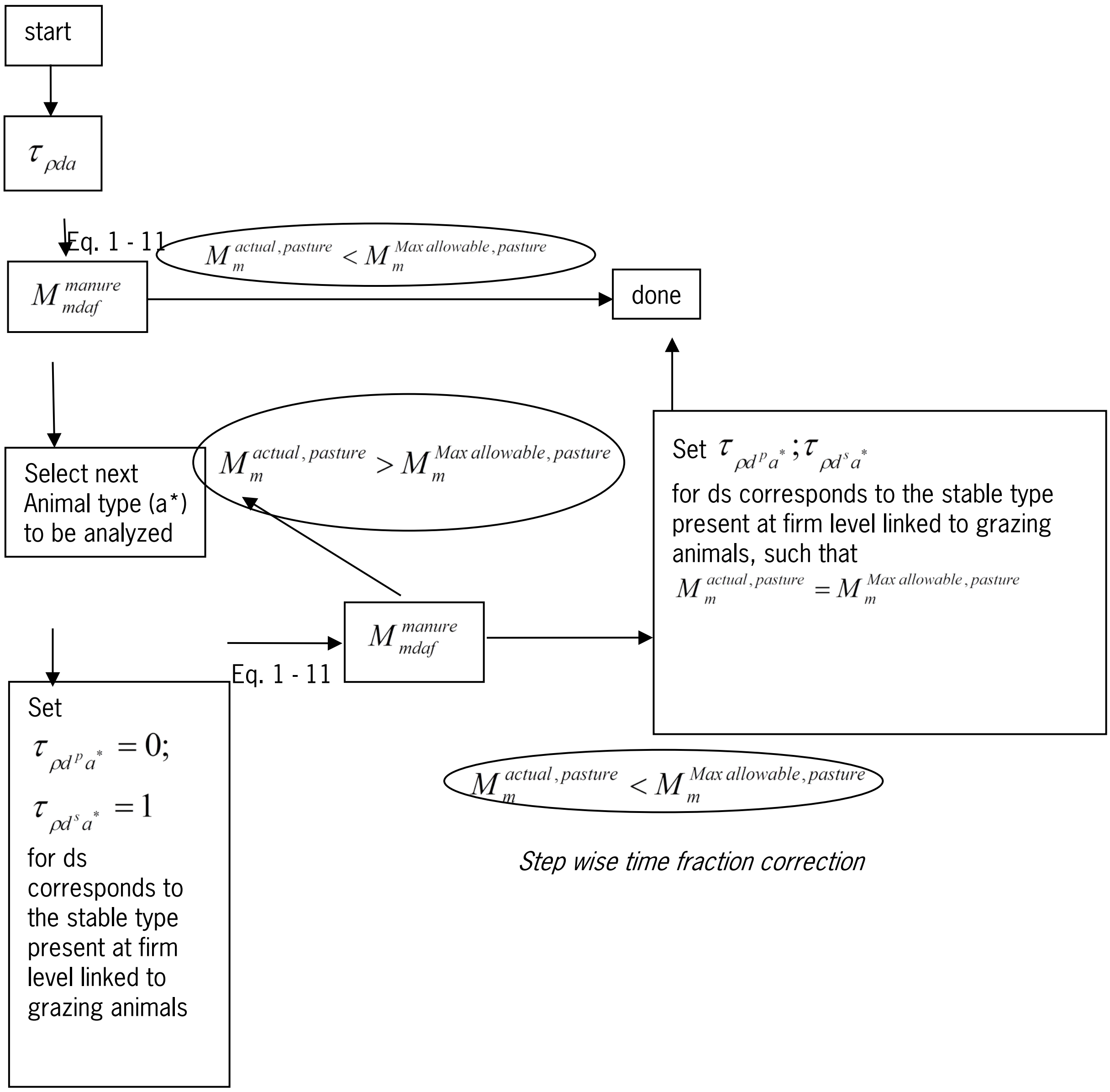


Figure 5.2: Graphical presentation of step wise time fraction correction

6 Input data and parameters

6.1 Introduction

This chapter describes the numerical inputs of MAMBO. In Section 6.2 the model specification is used as a starting point to indicate which data are required in each part of the model (for example manure production). The inputs are described in the same order as in chapter four and the same names are used as in Figure 4.1. In 6.3 the data elements are described again but the elements are categorized according to the underlying data source (for example the agricultural census). These data sources will be evaluated based on a set of criteria to give an indication of the quality and robustness of the data.

Numerical data is only one aspect of the data that enter into a model, albeit a very important one. Besides numerical data we also distinguish index classifications (the way the data is organized and the degree of detail therein) and information for controlling model processes. The index classifications have a direct bearing on the numerical data because the numerical data is defined over its indices, and each index has its specific classification. In Chapter 5 we discussed, some of the issues related to the indices and noted that membership of index sets is variable in most cases. A classification defines the index membership. In Section 6.4 we discuss the index classifications that play a role in MAMBO.

Model control is an important issue. It is sometimes related to numerical data. Depending on the way the data are organized, model processes will differ. In Chapter 3 on the design criteria, it is argued that information regarding this type of model control need to be separated from the model code. The model code obviously contains these control variables. The values that these control variables get is defined in the data and information parts of the modeling frame work. In Section 6.5 the control variables are described that are used to define MAMBO.

6.2 Data elements in different parts of the model

This section describes the inputs for the different parts of the model as specified in the previous chapters:

- Manure production;
- Maximum application amount;
- Manure excess;
- Manure transport and;
- Manure application.

6.2.1 Manure production

Manure produced on animal farms can be classified and processed separately in MAMBO. Sources of manure are distinguished based on the following parameters:

- Type and number of animals;
- Feed rations;
- Housing and grazing systems;
- Processing at farm level;
- Storage systems;
- Emission factors of housing, grazing and storage.

The combination of animal type and feed ration defines the manure and mineral excretion. Values on these excretions are an essential input for MAMBO. The excretion can take place at different locations. The manure can for example be excreted directly on the field, and stable manure can be stored or it can be processed at farm level into other products. In all these examples emissions take place. MAMBO needs inputs for these emission factors. The different input elements will be described in the next sections.

Type and number of animals

Monitoring studies

In MAMBO, each individual animal is the principle starting point for the calculations. However, in most applications animal categories at firm level will be the starting point, because of an absence of information at individual animal level. Instead of firm level data can also be specified at regional level. Information on the number of animals can be from any available source, but in the current situation the Figures will most often come from the Dutch agricultural census. For example, for the year 2005, 43 different animal categories are used from the Dutch agricultural census (see appendix 1 for a list of these categories). These are the animal categories that are described in the manure laws of 2005 (MINAS) and for which mineral excretions are available. The number of animal categories in the Dutch Manure Policy based on the Nitrate Directive (91/676/EEG) is larger.

Forecast studies

In forecast studies it is common practice to choose a base year in the recent past. The number of animals for the base year is then identical to monitoring studies. For the forecast year, MAMBO needs input about the changes in the number of animals between the base year and the forecast year. This is modeled as an index of change per animal category at national, regional level or firm level. Different sources can be used to model or estimate these indexes of change. For example, changes can be estimated by models such as DRAM (Helming, 2005) or APPROXI (Hennen, 1995) or can be based on expert judgments (the models are discussed more extensively in Chapter 7).

Feed ration

Animal excretion, manure as well as minerals, are highly dependent on the ration fed. The combination of water, protein and energy intake determines the excretion of the animals. In MAMBO every type of animal can be fed with one or more feed rations. For most model calculations so far, four different feeding systems are distinguished for grazing animals (Table 6.1).

Table 6.1: Common feed rations in MAMBO for grazing animals

Period (season)	**Amount of maize silage in ration**	
	High	**Low**
Grazing or summer season	Summer with maize	Summer with grass
Housing or winter season	Winter with maize	Winter wit grass

The lowest possible level of definition of ration in MAMBO is at animal level. In the current situation data is not available at that level of detail. In most calculations, ration data is defined at a regional level.

The input of rations is identical for monitoring and forecast studies. However, for monitoring studies the input is based on empirical data and for forecast studies on expert judgments. The empirical data are usually based on the Working Group Uniform Mineral and Manure Excretions (Werkgroep Uniformering Mestcijfers, WUM).

Excretion

Monitoring studies

The excretion of manure and minerals is based on ration categories and animal category. Although detailed excretions per animal could be modeled, the input for excretions are defined for each animal category and feed ration combination. Excretions refer to manure and minerals included in that manure. In the context of MAMBO minerals can also be defined as other elements such as: heavy metals, organic matter content, dry matter content, residuals of medicine and so on. In MAMBO it is possible to use two types of excretions at the same time:

- The legal standards of excretion or production and;
- The scientific calculated or measured excretions.

Each year, the WUM estimates the manure excretion and the mineral content of nitrogen, phosphate and potassium (Van Bruggen, 2007). The excretion factor are estimated for animal categories. The excretion Figures estimated by the WUM are most often the basis for monitoring studies. For grazing animals there is a diversification in feeding systems as stated before. The WUM-excretions are in MAMBO used as the scientific or measured excretions. These data are only available at national level.

However in the current Dutch situation, the mineral excretion of grazing animals is based on fixed values as decreed by the ministry of Economic Affairs (EZ). These excretions are used as the legal standards. For Dairy farmers the legal mineral excretion of dairy cows depends on the urea content and milk yield. This is also modeled in MAMBO. For each farm, the excretion of milking cows is calculated based on the milk production and the urea content in the milk at that specific farm.

Forecast studies

The required inputs on excretion factors are identical in forecast studies and monitoring studies, only the source of the inputs differ. Excretion inputs for forecast studies is often based on studies of feeding experts or expert judgments of feeding experts.

Housing systems

Every animal category is assigned to one ore more housing systems. In MAMBO there is no limit on the amount of housing systems that can be used. The only limit is the availability of data or the project budget. If data would be available on animal or farm level they can be used.

Monitoring studies

Every four years, the agricultural census makes an inventory of housing systems at farm level. These data are commonly used in monitoring studies. For dairy cows the results are used at farm level and for other animal categories the data are used at regional level, although MAMBO makes it possible to use farm level specific data for all categories. The most recent inventories of housing systems dates back to 2004 and 2008. The 2004 inventory contains data for the following housing systems:

- Dairy cows: ten housing systems (six cubicle housing systems from which two with low ammonia emission; two types of tied housing including one with low ammonia emission; one type of deep litter and one for other housing systems).
- Dairy calves and heifers: the same ten housing systems as for dairy cows.
- Fattening pigs: four housing systems.
- Sows and piglets: four housing systems.
- Laying hens: younger than 18 weeks, seven housing systems (two batteries; two aviary; two ground housing and one other).
- Laying hens : 18 weeks and up, fourteen housing systems (two batteries with slurry; six batteries dry manure; two aviary, two ground housing and one other).
- Broilers: three systems (two traditional and a single low ammonia emission housing).

Forecast studies
For forecast studies the same type of data is required as input for MAMBO. The common practice is that based on the results of the last inventories and the rules of the government affecting the future housing systems, experts make estimations of the expected housing systems in the forecast year. These expectations about the occurrence of housing systems in the future are the inputs for MAMBO.

Grazing systems

The amount of time grazing animals spend in the pasture or in the stable determines the amount of manure and minerals produced in the stable or placed on grassland. In MAMBO this information could be used at farm level, if available.

Within the Dutch Farm Accountancy Data Network (a sample of 1500 agricultural and horticultural farms) a yearly inventory is made of the grazing systems in use. Starting in 2005, also information on the grazing period is recorded. Each year, this inventory is used to calculate the occurrence of grazing systems at regional level. These calculations are used in monitoring studies. For forecast studies estimations can be made if major changes are expected, but it is common to use the results of the last inventory.

Storage systems

For every kind of manure (animal type * housing system) MAMBO needs information about the share of the produced manure that is stored outside the housing system. This share can also be zero. If manure is stored there should be at least one storage system. There is no limit on the number of storage systems in MAMBO, but the model needs inputs on storage time and costs of storage for each combination of manure category and storage system. The model can calculate with farm specific factors.

The inventory of outside storage systems was rather outdated. For a long time, information from the agricultural census 1997 was used. The results at farm level of this census were used in the calculations for monitoring and forecast studies. In 2007 a new inventory at farm level was made in the agricultural census. The results of this inventory are used for calculations starting from 2008. In 2011 a new inventory was made that will be used as of 2012.

Emission factors of housing, grazing and storage

A main objective of Mambo is the calculation of nitrogen emissions to the air. In MAMBO it is possible to calculate two types of emissions at the same time:
- The legal standards of emissions for housing and storage and;
- The scientific calculated or measured emissions.

Legal standards of emissions at housing and storage
These emissions are combined with the legal standards of excretion or production. These are the total emissions of all nitrogen gasses from housing and storage and they differ for different types of animal and housing systems.

The scientific calculated or measured emissions
In the calculations for the production of manure four different locations / processes of emissions are distinguished: emissions in stables, emissions in pastures, emissions during storage and emission during processing at farm level.
In MAMBO four types of emissions are distinguished:
- Ammonia (NH_3);
- Dinitrogen oxide (N_2O);
- Nitrogen gas (N_2) and;
- And nitrogen oxides (NO_x).

MAMBO requires input data on emission factors for every combination of animal type and housing system, storage system and emission type. There is only one emission factor at national level for manure that is dropped on grassland: ammonia emission. For processing (not implemented yet) the emission factor is a fraction of the mineral content at the time of handling.

In the past, the emission factors for ammonia were supplied by the Dutch Environmental Assessment Agency (PBL). These factors were based on research results. Nowadays a committee (Working group Ammonia emissions from the CDM) determines which emission factors for ammonia should be taken into account. Other emission factors that are used are taken from Oenema *et al.* (2000). As of 2011 for ammonia emmissions a new methodology is applied based on total ammonia nitrogen (TAN)

6.2.2 Maximum application amount

Required data elements:
- Hectares of crops;
- Soil type;
- Standards;
- Mineral effect coefficient;
- Minimum fertilizer amount;
- Acceptation degree.

Hectares of crops

The lowest possible level of calculation in MAMBO is on parcel level, but normally MAMBO calculates at farm level. It is also possible to use information at a higher levels, such as municipality level or regional areas. There are no limits to the number of crops MAMBO can handle.

For monitoring studies the results of the agricultural census on crop area per crop and per farm are used.

In forecast studies it is common practice to choose a base year in the recent past. For the base year data from the agricultural census are used. For the forecast year, MAMBO needs input about the changes in the areas of crops between the base year and the forecast year. This is modeled as an index of change per crop category at national, regional level or firm level. Different sources can be used to model or estimate these indexes of change. For example, changes can be estimated by models such as DRAM (Helming, 2005) or APPROXI (Hennen, 1995) or can be based on expert judgments (the models are discussed more extensively in Chapter 7).

Soil Type

Some input parameters are dependent on the type of soil. For such input parameters (i.e. legal fertilizer standards, application utilization) it is necessary to distinguish the type of soil. MAMBO can handle soil type information at crop level per farm, but also higher aggregation levels are possible. The number of soil types in MAMBO is not limited. The soil types clay, sand, peat and loess are used in the Dutch Manure Legislation since 2006. Alterra provides a map with the soil distribution. This information is merged with the Farm Plots Registration (BRP, LNV-DR). This results in a soil distribution for each individual farm. This distribution is used in MAMBO when the legal soil types are used in monitoring or forecast studies.

As of 2011 soil type alone is not sufficient since the standards for phosphate are based on soil phosphate levels, hence soil quality classes have been introduced. The information concerning the soiul quality at farm level is taken from the regulatory agency (Dienst Regelingen) who provide detailed information on prcelsize and soil quality indicators as provided to them by farmers.

Standards

The standards MAMBO needs (monitoring and forecast studies) are in kg per ha crop per soil type per regional area. The Manure Legislation 2006 distinguishes four different legal standards. These are standards (limits) for nitrogen and phosphate from animal manure and nitrogen and phosphate from all fertilizers (all organic manure and artificial fertilizers). All four are used to determine the amount of manure that can be applied on crops. The legal fertilizer standards are provided by EZ (LNV) with the dimension kg mineral per hectare per crop per soil type. For monitoring studies the legal standards of the Manure Legislation are used in MAMBO. In forecast studies MAMBO calculates with legal standards that are expected in the forecast year.

Mineral effect coefficient

MAMBO requires input data on two mineral effect coefficients: the legal mineral effect coefficients and the agriculture mineral effect coefficients. The legal mineral effect coefficient is used to calculate how much animal manure can be applied within the legal fertilizer standards.

Minerals applied early in the year will be absorbed more than minerals that are applied at the end of the year. This is called the agriculture mineral effect coefficient. The amount of minerals that are effectively absorbed by crops determines the amount of artificial fertilizer that can be applied.

The legal mineral effect coefficient as required by MAMBO is a fraction per mineral per manure type, time of spreading, grazing system and own or off farm manure.

The agricultural mineral effect coefficient is a fraction per mineral, crop, time of spreading and fertilizer category. For Nitrogen the mineral effect coefficient is also per Nitrogen fraction (see Chapter 7 for a description of an application). The information on effect coefficients that is normally used is based on scientific research and expert judgment (Dijk, 2004; Willems, 2007).

Minimum fertilizer amount

The minimum fertilizer amount is used to calculate how much animal manure can be applied within the legal fertilizer standards. MAMBO needs this information per crop and mineral. The information as used in MAMBO is based on scientific research and expert judgment from PPO (Dekker, 2007).

Acceptation degree

The acceptation degree of manure application describes the extent to which the most restricted standard will be reached. It is only relevant for off-farm produced manure. For on-farm produced manure it is assumed that the limits will be filled up. The dimension of acceptation degree is fraction per crop per region.

The acceptation degrees for monitoring studies are obtained from the Dutch Farm Accountancy Network (BIN) in combination with information from the ministry of Economic Affairs about the use of off farm manure in agriculture.

The acceptation degree for forecast studies is normally obtained from workshops with farmers and experts on manure application. In these workshops, farmers are asked how much manure they will use given certain legal manure standards in the forecast year.

6.2.3 Manure excess

For this process no extra input is needed from what already is described by manure production and maximum application amount.

6.2.4 Transport

Required data elements:

- Export outside Dutch agriculture;
- Processing;
- Distance between regional areas;
- Distribution costs.

Export outside Dutch agriculture

Export outside Dutch agriculture is defined as:

- Application of manure on natural grounds;
- Application of manure on land of hobby farmers or private people;
- Export of manure to neighboring countries.

MAMBO requires this information in terms of amount of manure at national level per type and type of export.

For monitoring purposes the data are acquired from the ministry of Economic Affairs. It is based on transport registration forms of transport companies. For forecast studies experts are invited to make expert judgments of the export outside Dutch agriculture for the forecast year.

Processing

Part of the surplus manure will be processed in order to make transportation more profitable. Some of the processed products will be used in agriculture and some processed products will be exported or used outside agriculture. Processed manure is divided into different manure products with fixed fractions per process and manure category for the amount of manure and minerals. During the processing also some mineral losses take place. Therefore MAMBO requires the following information:

- The amount of manure per type of manure that can be processed per type of processing;
- The products of processing per type of processing;
- The fractions of the resulting types of manure after processing;
- The fractions of minerals and manure that are emitted by processing per type of manure, mineral and type of processing.

The technical data about the processing system and the resulting manure categories are from experts on the processing of manure. For monitoring studies, the amount of manure processing come from inventories from the CBS (Van Bruggen, 2007). Data for forecast studies about the amount of manure that will be processed is based on expert judgments.

Distance between regional areas

To calculate the variable costs of manure transport, the distance between regional areas is necessary. The longer the distance the more it costs to transport manure. MAMBO needs this distances in kilometers between regional areas.

Distribution costs

The manure market as modeled in MAMBO is based on economical principles. There is a supply and demand for manure and there are sellers and buyers. The cost elements required in MAMBO are:

- Fixed costs for transportation to factories per kg of manure per manure kind;
- Fixed costs for transportation between regional areas per kg of manure per manure kind;
- Fixed costs for storage per kg of manure per manure kind, storage kind per year;
- Variable costs per km and kg of manure for transported manure per kind of manure;
- Application costs per kg of manure per manure type (slurry or solid) and application technique;
- Process cost of manure processing per kg of manure per manure kind and process;
- Value of mineral content per kg of manure per manure kind per crop (Not implemented yet in MAMBO) and;
- Transaction costs manure transport per kg of manure per manure kind.

The costs are based on research conducted by the LEI.

6.2.5 Application of transported manure and artificial fertilizer

Required data elements:

- Mobile, readily mobile and non-mobile nitrogen
- Application technique
- Season of manure application
- Agriculture fertilizer standards
- Ammonia emission factors by application of manure

Nitrogen is divided into three different fractions which can be characterized by the time it takes for crops to absorb it: mobile, readily mobile and non-mobile nitrogen. For each type of manure MAMBO requires information on the fractions. In the current situation, this information is based on Schröder *et al.* (2004, 2005).

Application technique

Manure is applied on crops with different application techniques. MAMBO requires information on the occurrence of application techniques as a fraction of the amount of applied manure per technique, area, crop and manure type (slurry or solid). The number of application techniques is not limited in MAMBO. For monitoring studies data from the agricultural census are used. The agricultural census provides an inventory of application techniques at farm level every five years. Table 6.1 provides the results at national level of the last inventory in 2005 for grassland and arable land (Hoogeveen *et al.*, 2006).

Table 6.1: Distribution of manure application techniques

Manure application technique	Applied to	Percentage
Closed slot shallow injection and deep injection	Grassland	56 %
Open slot shallow injection	Grassland	14 %
Trailing shoe / trailing hose	Grassland	23 %
Other systems	Grassland	7 %
Injection	Arable land	34 %
Trailing shoe / trailing hose	Arable land	6 %
Surface spread and incorporated in one track	Arable land	27 %
Surface spread and incorporated in two tracks	Arable land	27%
Other systems	Arable land	6 %

For forecast studies experts make predictions about the techniques that will be used in the forecast year and these predictions are used in MAMBO.

Season of manure application

The mineral effect coefficient depends on the season of application. Manure application during spring or summer is more efficient than during autumn or winter.

MAMBO requires information on the fraction of manure applied in spring and summer per crop and region. For monitoring and forecast studies this information is determined by expert judgment and game simulation with farmers.

Agricultural fertilizer standards

To calculate the amount of applied fertilizer, information on the amount of fertilizer what will be applied is required. There are two possibilities from which one has to be chosen:

- Realized fertilizer amount in kg per ha per mineral per crop per regional area;
- Agricultural fertilizer standards in kg per ha of minerals that could be absorbed by the crops in the first season. MAMBO needs this information in kg minerals per ha per soil type per crop.

In monitoring studies the realized fertilizer amount is normally used and in forecast studies the agricultural fertilizer standards are most often used. The realized fertilizer amounts are based on the Dutch Farm Accountancy Data Network (BIN). The agricultural fertilizer standards are based on the data of PPO (Van Dijk, 1999).

Ammonia emission factors by application of manure

This information is necessary to calculate the ammonia that is emitted during the application of animal manure and artificial fertilizer and to calculate the soil loads with minerals.

For animal manure MAMBO needs this information as a fraction of the amount of N-Tan content (Poultry UAN) of manure per application technique. For nitrogen fertilizer MAMBO only needs an emission factor as a fraction of the amount of fertilizer amount that is applied at national level.

6.3 Data sources providing data elements

This section gives a description of the data sources that are commonly used for calculations with MAMBO on monitoring of national manure and ammonia inventories for the Dutch government.

6.3.1 Agricultural census

Data elements

- Number of animals at farm level;
- Crop hectares at farm level;
- Housing systems at farm level;
- Storage systems at farm level;
- Manure application techniques at farm level.

Short description of source

The agricultural census is a yearly census of all farms above a certain threshold (3 ESU) in the Netherlands. Farms are obliged to provide data. Not providing data can results in penalties.

Evaluation of source

The agricultural census provides a very detailed description of agricultural activities on individual farms. The data about animal numbers and crop area are updated every year and the data about housing, storage and application once in the four to five years. The quality of the data is supported by administrative sanctions for not providing data in time or providing incorrect data.

6.3.2 Farm accountancy data network (Bedrijven-informatienet)

Data elements

- Use of artificial fertilizers;
- Application utilization for to calculate acceptation degrees;
- Grazing systems and time of grazing.

Short description of source

The EU Farm Accountancy Data Network (FADN) requires the Netherlands to yearly send bookkeeping data of 1,500 farms to Brussels. This task is carried out by LEI and CEI. The data sent to Brussels mainly involves technical and financial economic information. For national policy purposes additional data is collected, such as pesticide use, manure production, nature management, non-farm income and rural development. The population (field of survey) of the FADN is defined as all farms above the threshold of 16 European Size Units (ESU). A stratified random sample is drawn, in which economic farm size and type of farming are used as stratification variables.

Evaluation of source
The FADN system provides very detailed information on the structure and performance of farms. It is a sample of farms. The farms are drawn from the agricultural census in order to provide a representative group of farms.

6.3.3 Farm Plots Registration (Bedrijfs Registratie Percelen, BRP)

Data elements
- Crop allocation.

Short description of source
Every farmer is obliged to register the crops and the location of the crops with EZ-DR (LNV-DR). This is an obligation for the European Union (EU) in order to receive income support. If another crop is grown on the same plot during the same year this also has to be registered.

Evaluation of source
BRP contains very detailed information on the location and type of crop. However, this information is not always compatible with the agricultural census, because the latter is an indication of a given moment in time while the BRP is a dynamic source. Therefore BRP is only used to determine the soil distribution per firm and not per crop, if an exact match is not possible.

6.3.4 Regulatory agency (Dienst regelingen)

Data elements
- Soil quality classes.

Short description of source
Every farmer is obliged to register the phosphate levels in their soils based on laboratory results if they do not want their fields to be categorized in the highest phosphate class which has the strictest norms concerning allowable phosphate levels in fertilizers.

Evaluation of source
The data of DR contains very detailed information on the size of parcels, type of crop and the relevant indicator (PAL or PW numbers). However, this information is not always compatible with the agricultural census and BRP, because the former is an indication of a given moment in time while the BRP is a dynamic source, while the data of DR is static valid for three years and not necessarily monitored at the same time as the agricultural census. Matches are made as best as possible and firm level averages are used when information is incompatible. For missing data the category unknown is used, which is a valid choice since farms are not obliged to hand in this information. The category unknown is treated as the highest class in terms of phosphate levels in the soil.

6.3.5 Manure distribution

Data elements
- Use of off farm manure in agriculture;
- Export of manure outside Dutch agriculture.

Short description of source
For all manure that is transported a transport form has to be filled in. On this transport form information is available on: type and amount of manure, the mineral content, where the manure is loaded, the destination of the manure and by whom it is transported. All these transport forms are send to the ministry of Economic Affairs (EZ-DR: Dienst Regelingen) and they produce statistics at national and regional level. These data are also published on Statline, the online database of Statistics Netherlands (CBS).

6.3.6 WUM excretions

Data elements
- Feed rations;
- Scientific calculated or measured excretions.

Short description of source
Each year the working group uniform mineral- and manure excretions (WUM) updates the manure and mineral excretion per animal type. Each September this group evaluates new proposals for these excretion values and improvements of the calculations (Van Bruggen, 2007).

Evaluation of source
The WUM-excretions are at national level and for the grazing animals the excretion depends on the feed ration. The four different feed rations the WUM uses are also used in the MAMBO calculations. The rations differ in the amount of grass, grass silage, maize silage and concentrates an animal gets.

6.3.7 Manure legislation

Data elements
- Legal standards of amount of manure application;
- Legal standards of animal manure production;
- Legal standards of mineral effect coefficient.

Short description of source
January 2006 a new law was implemented in the Netherlands which was published in the ‘Staatscourant’ of November 2005. A few rules and data are updated in 2006 (Staatscourant 29 juni 2006). Rules were updated again in 2010 with different phosphate application norms for soil fertility of phosphate.

6.3.8 Advice guidelines about manure application

Data elements
- Minimum fertilizer amount;
- Agriculture fertilizer standards;
- Agriculture mineral effect coefficient;
- Mobile, readily mobile and non-mobile nitrogen.

Short description of source
Once in the four or five years Applied Plant Research (PPO) updates advices on the application of fertilizers on agricultural and horticultural crops.

6.3.9 Statline

Data elements
- Amount and kind of processed manure

Short description of source
Statline is an online internet database of Statistics Netherlands (CBS). Information on manure is updated yearly. The data on manure distribution from the ministry of Economic Affairs are also published in the online database. The publication of this information is too late to use in the inventory studies, therefore the data for the inventory studies are directly received from the ministry of Economic Affairs. Also the final information on the amount of manure processing is too late to use in the inventory studies. Therefore preliminary is used in the inventory studies.

Evaluation of source
The information on the amount of processed manure is gathered from each processing plant by means of a telephone interview.

6.3.10 Research results of Wageningen UR

Data elements
- Technical data about processing of manure (products, losses, splitting fractions);
- Distance between regional area's;
- Distribution costs;
- Season of manure application.

Short description of source
Different research reports of WUR-institutes.

Evaluation of source
When new research results are published in WUR-reports, the corresponding elements in MAMBO are updated.

6.3.11 Research results Netherlands Environmental Assessment Agency

Data elements
- Emission factors of housing, grazing, storage and application of manure.

Short description of source
The task of the Netherlands Environmental Assessment Agency (PBL) in the emission inventories was to update the emission factors. The information to update the emission factors comes from new research results on ammonia emission. Since 2007 this task is done by the working group: emission factors.

Evaluation of source
The working group emission factors published the last update of the emission factors through PBL in 2008.

6.3.12 Working group on national NH3 emissions (NEMA)

Data elements
- Emission factors of housing, grazing, storage and application of manure.

Short description of source
One of the task of the Working group on national NH_3 emissions (NEMA) is to update the emission factors. The information to update the emission factors comes from new research results on ammonia emission.

Evaluation of source
The working group emission factors will publish an update of the emission factors in 2008.

6.3.13 Overview of data sources

In Table 6.2 we observe a summary of the most important data sources discussed above.

Table 6.2: Overview of data sources

Source	**Supplier**	**Frequency**	**Admininistrative/ statistical**	**Sample vs. census**	**Primary or processed data**	**Quality control**	**Bias**
Agricultural census	CBS	Yearly	Administrative/ statistical	Census	Primary	Administrative sanctions	Farms larger than 3 dsu
FADN / BIN for use of artificial fertilizers, acceptation degrees and application utilization	LEI	Yearly	Statistical	Stratified sample	Primary and processed	Sampling procedures Data controls (input, consistency etc.) Quality check	Farms represented larger than 16 esu
BRP	LNV-DR/ ELI-DR/ EZ-DR	continuing	Administrative	Registration	Primary data	Administrative sanctions	Farms larger than 3 dsu
Soil distribution	Alterra	Unknown	Administrative	Sample	Processed		
Application emission factors	A&F	Unknown	Emperical		Primary		
Fertilizer mineral fraction, fertilizer recommendation	PPO	Unknown	Emperical		Primary		
Transaction costs, transportation costs, process costs, export costs	LEI	Unknown	Emperical		Primary and processed		
Excretion volume dairy cattle, mineral excretion (urea), legal standards, legal mineral coefficients	LNV-DL/ ELI-DL/ EZ-DL	Unknown	Administrative		Primary	None	
Manure excretion	WUM	Yearly	Emperical	Sample	Processed		
Artificial fertilizer	LEI	Unknown	Emperical		Processed		
Transport, export and process manure	LNV-DL/ ELI-DL/ EZ-DL /CBS	Yearly	Administrative		Processed		
Urea content and milk production	Dutch Dairy Board	Continuing	Administrative	Sample	Primary		

6.4 Index classifications

The indices over which the numerical data is defined are summarized in Table 6.3. The list is not extensive in terms of available classifications as specific classifications have been used for specific research projects and new classifications can be created on demand. The number of elements in classification as reported in the last column gives an indication of extent of data requirements in MAMBO.

Table 6.3: Index classifications

Index name	**Symbol**	**Description**	**Classifications**	**Elements in classification**
iAnimalCategories	a	animal categories	AC_MAM AC_MAMBO AC_MAMBO2006 AC_MAMBO2008 AC_MAMBO2010	10 41 43 35 35
iAnimalClasses	a	animal classes	ACL_MAMBO	11
iApplicationtype		method for application of manure to fields	AT_BASIS AT_1990 AT_BASIS2010	7 2 11
iCountry		three letter country acronym	CNT_BASIS	6
iCropClasses	c	aggregated crop identifier	CCL_BASIS CCL_MAM CCL_STONE	9 9 26
iCrops	c	crop identifier	CR_MAM CR_MAMAFC CR_MAMBO CR_MAMBO2005A CR_1990 CR_MAMBO2005B CR_MAMBO2008 CR_MAMBO2009 CR_MAMBO2009A CR_MAMBO2010 CR_StatLine_Small	9 8 95 111 78 174 178 179 179 186 1
iDepartmentCategories	d	Housing and Department Categories	DC_BASIS DC_MAM DC_MAMBO DC_MAMBO2006 DC_MAMBO2008 DC_STONE DC_1990 DC_1990NEMA	30 30 33 33 44 34 24 30
iDerogation		derogation	D_BASIS	2
iDR_ManureCategories	f	Manure categories of Dienst Regelingen	DRM_NLD DRM_MAMBO2006	72 55
iEmissionFactors	e	emission factors	EM_Basis	4
iFertClasses_Reports	f	Aggregation of fertilizer classes	FCR_MAMBO FCR_MAMBO2006	6 7
iFertClasses_ER	f	Aggregation of fertilizer classes	FCE_MAMBO2006	27
iFertDest_Sector		Sectors for fertilizer transport destinations	FDS_Basis	3
iFertDestination_RA		Group of regional areas for fertilizer transport destinations	FDR_Basis	3
iFertilizerCategories	f	Fertilizer categories	FC_MAM FC_MAMBO FC_MAMBO2006 FC_MAMBO1990NEMA FC_MAMBO2008	59 133 147 184 184

Index name	Symbol	Description	Classifications	Elements in classification
iFertilizerClasses	f	Aggregated fertilizer categories	FCL_MAM FCL_MAMBO2008 FCL_STONE	56 35 31
iFirm	h	Firm identifier	NLD1990F NLD2002F NLD2005F NLD2006F NLD2007F NLD2008F NLD2009F NLD2010F	119955 89580 81830 74973 72616 71419 69588 68970
iMestClean		CLEAN manure categories used for MAMBO-STONE conversion tool	BaseCLEAN	12
iMestSTONE		STONE manure categories used for MAMBO-STONE conversion tool	BaseSTONE	4
iNComp		STONE N mineral fractions used for MAMBO-STONE conversion tool	BaseSTONE	3
iNMinOrg		STONE N mineral fractions used for MAMBO-STONE conversion tool	BaseSTONE	2
iSubMestSTONE		STONE manure aspect type categories used for MAMBO-STONE conversion tool	BaseSTONE	2
iLU		land use categories	Basis	3
iExcretion		excretion mineral period identifiers for TAN data preparation	BasisTAN2008	15
iMyDC		excretion department identifiers for TAN data preparation	BasisTAN2008	5
iMyRegion		region identifiers for TAN data preparation	BasisTAN2008	3
iLinkClasses		Classes to link DR_ManureCategories with FertilizerCategories	LC_BASIS LC_MAMBO2006	26 27
iManureAspectType		Characteristic of manure	MAT_BASIS	5
iManureFactoryCategory		Factory types for manure processing	MFC_BASIS	1
iManureMarketRegions		Aggregation of regional areas	MMR_BASIS	11
iManureProcess		Types for processing manure	MP_BASIS	6

Index name	Symbol	Description	Classifications	Elements in classification
iManureSource		Origin of manure	So_BASIS	2
iManureStorageCat		Types of manure storage	MSC_BASIS	3
iMilkQuantCategory		Ranges of milk quantity	MQ_BASIS	22
iMineralFraction		Fractions of minerals	MF_BASIS	4
iMinerals		Mineral identifier	M_BASIS	3
iMunicipalities		Municipality identifier	mun_NLD1986 mun_NLD1990 mun_NLD1999 mun_NLD2002 mun_NLD2005 mun_NLD2006 mun_NLD2007 mun_NLD2008 mun_NLD2009 mun_NLD2010	708 666 540 498 469 460 445 445 443 433
iPdiff	q	Soil quality identifier with respect to fosfate state	Pdiff_BASIS	4
iPolicyRegionST		Aggregation of regional areas for reporting purposes	DOM_ST9 EMW2012	9 9
iProcesses		Process identifier	proc_BASIS	6
iProvince		Province identifier	prov_BASIS	12
iRations		Ration identifier	RT_BASIS RT_MAM	21 10
iRegionalAreas		RegionalArea identifier	RA_BASIS	33
iRegions		Aggregation of regional areas	R_BASIS	2
iSeason		Season identifier	Sea_ASIS	4
iSQ	q	Soil quality identifier	SQ_BASIS	4
iSoilType	s	Soil type identifier	ST_BASIS ST_MAM ST_MAMBO2006 ST_STONE	7 7 4 7
iUreumCategory		Range of urea contents	UC_BASIS	29

6.5 Control variables

The control variables are the project and user defined settings that define the way the model is run. The control variables can be divided into a number of different types. There are scenario specific control variables that define what constitutes a scenario. There are control variables that define the set structure of numeric data, depending on how the data is defined. There are control variables that set specific calculation rules and control variables that switch certain aspects in the model on and off. Finally there are also meta information control variables that indicate the project at hand, the scenario that is run etc.

In Table 6.4 the original control variables of MAMBO 1.x are highlighted. Under MAMBO 2.x the number of control variables has increased tremendously. A full list is provided in Appendix 3.

Table 6.4 Model meta information control variables

Control variable name	Description	Values
DataYear	year the data is based on	<yyyy>
scenario	scenario identifier	<:string>
project	project identifier	<:string>
Country	country for which MAMBO is run	{NLD}
GetNewData	Is a data update needed	{ Yes,No }
UDVariant	is there an allowance	
OutputDir		
OutputRules		{ Classic, STONE, Milieubalans, MonMestmarkt }
JustOutput		{ Yes, no }
UseAcceptationDegree	Wether or not acceptation degrees have to be used in order to determine the application room for foreign manure	{ Yes, no }
AcceptDegreeCalc	Calculation types for adjusting (or not) the acceptation degrees	{ MAM, Storage, Adjusted, ChangeSlow, ExpandFix, ExpandFixA ,ExpandFlex, ExpandPoints }
PostRBFM	Initializing additional modules to take exceptions for manure policy into account.	{ Agric, Fixed, MarkBode }
Excretion	How the mineral excretion is calculated.	{ ureumfixed,ureumcalc,ration }
FertMinContent	How the mineral content of manure categories id determined	{ forfaitair, scientific }
LegalManureStandard	Distinction in manure standards	{ normal, soiltype }
Standards2Use	Wether one or more standards have to be integrated	{ LMS, LMS_LFS_MFA }

6.6 Calibration of the model for each application

Micro-simulation models using all available firms are by definition calibrated in terms of the input data from the agricultural census. Not all data is in the agricultural census. Calibration of the model is done at a number of locations:

- The agricultural census does not provide detailed information on feeding strategies for grazing animals, such as outsourcing grazing or non-grazing husbandry of grazing animals. Hence there may be a discrepancy between pasture availability and number of grazing animals at firm level. Grazing levels are calibrated using the agricultural census data (self calibration). Outsourcing is not taken into account and the animals are assumed to be kept in animal housing. (Current data availability does not permit calibrating on outsourcing).
- The mineral production per kind of animal for monitoring projects are calibrated with the statistics of the CBS about manure production.
- The spatial equilibrium model is calibrated at manure region level by imposing relative distribution of phosphate demand in the data of the regulatory agency (EZ Dienst Regelingen) at manure region level on the manure distribution.
- For a fertilizer application module, artificial fertilizer use statistics provided by the central bureau of statistics (CBS) is combined with data from the Dutch Farm Accountancy Data Network, to get manure region and crop class specific artificial fertilizer application figures.

7 Output and applications

7.1 Introduction

This chapter presents the main reporting variables of the MAMBO model. Due to flexible architecture, in principle it is possible to report any variable that is calculated in the model. Section 7.3 gives a description of some applications of the MAMBO model. A distinction is made between applications on monitoring, policy analysis and ad-hoc research. For some research questions MAMBO is used in cooperation with other models and tools. Therefore Section 7.4 gives a short overview of models with which MAMBO interacts.

7.2 Output of the MAMBO model

Table 7.1 presents some of the main output categories of MAMBO. The level of aggregation provides some idea on the normal level of output. The level of aggregation is in principle flexible in the MAMBO model. Aggregation to water bodies (in relation to the water framework directive), provinces, municipalities, nature areas or other regional divisions is possible if information on the belonging of individual farms to these regions is added to the model.

Table 7.1: Main reporting variables. See also Figure 7.1

Output variable	**Unit**	**Level of aggregation**
Number of animals and hectares	Units and hectares	Farm level National 31 manure regions Other regional division
Production of manure	kg manure and minerals per type of manure	Farm level National 31 manure regions Other regional division
Farm surpluses	kg manure and minerals per type of manure	Farm level National 31 manure regions Other regional division
Hectares without application of manure	hectares	Farm level National 31 manure regions Other regional division
Destination of farm surpluses	kg manure and minerals	National 31 manure regions Other regional division Abroad
Ammonia emission animal manure and artificial fertilizer	kg emission from housing /grazing/storage/ processing/application per type of manure	Grid 5 * 5 km National 31 manure regions Other regional division
Application of animal manure in kg/ha	kg minerals per crop and soil type, own produced manure and off farm manure	Farm level National 31 manure regions Other regional division

Output variable	Unit	Level of aggregation
Application of artificial fertilizer in kg/ha	kg minerals per crop and soil type	National Other regional division 31 manure regions
Transport of manure within, between regions and abroad	Kg of manure and distance	National 31 manure regions Export
Processing	Kg of manure	National 31 manure regions
Costs and or earnings of manure distribution, processing and application	Euro's per kg of manure type	National 31 manure regions Other regional division
Infra structure	Number and size of storage types; Number and size of manure factories; Number and size of application units; number and size of transport units	National 31 manure regions Other regional division

Dimension of the output (Animal types, crop types, soil types, type of housing, storage system, application system, etc.) is the same as the dimension of the input (Chapter 6) for every level of aggregation.

Figure 7.1: Allocation of 31 manure regions to non-concentration region, concentration region East and concentration region South.

7.3 Applications of the MAMBO model

7.3.1 General

MAMBO and its predecessor MAM are used for many applications. The main categories of applications are (1) monitoring, (2) forecasting of the Dutch manure situation and ammonia emissions (3) ad hoc studies.

Monitoring

- Dutch Ammonia Emission Inventory: since the end of the ‘80’s, up till 2010 the yearly Dutch ammonia emission inventory is established in cooperation with the Netherlands Environmental Assessment Agency (PBL and its predecessor MNP), (MNP, 2006a). Section 7.3.2 describes some results; As of 2011a national consensus model for national emissions of ammonia (NEMA) is in use (Velthof *et al*, 2009b). NEMA uses information from MAMBO since it cannot itself calculate application levels. And needs those for regional disaggregation of national results.
- Situation on the Dutch manure market: since 2006, the yearly situation on the Dutch manure market is established (Luesink *et al.*, 2007, 2008b, 2009, 2010, 2011; De Koeijer *et al.,* 2011). Section 7.3.3 gives some results of these studies.

Forecasting studies are for instance

- Prediction of the Dutch ammonia emission in 2010 (Hoogeveen *et al.*, 2003); and 2020 (Vrolijk *et al.*, 2009b).
- Forecast studies of the Dutch manure situation (Staalduinen *et al.,* 2002; De Hoop *et al.,* 2004; Luesink *et al.,* 2004; Luesink *et al.,* 2007). Section 7.3.4 gives a summary of the results of Luesink *et al.* (2007).
- With MAMBO the soil loads with minerals are calculated as input for the STONE-model. STONE calculates the losses of minerals to ground and surface water (Willems *et al.,* 2005 and 2007). Section 7.3.5 gives some results of the last study.
- Exploration of the abolishment of animal quota (Baltussen *et al.,* 2010; Vrolijk *et al.,* 2010).
- Effect of animal feed on Phosphate emissions (Kortstee *et al.,* 2011).
- General perspectives of Dutch agriculture towards 2020 (Silvis *et al.,* 2009).

Ad hoc studies: MAMBO is also used for regional and international studies, for instance:

- Mineral balances at regional level for Dutch provinces (Luesink *et al,* 2000) and;
- Impacts of fabricated amino-acids in concentrates at nitrogen losses in west European countries (Brouwer *et al.,* 2001).

Examples of some of these applications will be described in more detail in the following sub-sections. The purpose of these descriptions is to give an idea about the range of research or policy questions for which the model is relevant.

7.3.2 The Regionalized Dutch ammonia emission inventory

The results of the ammonia emission inventory are published in many documents and publications at different aggregation levels, for instance:

- Publications from MNP Milieubalans (MNP, 2006b) and Milieucompendium (MNP, 2005): national results;
- Public database of Pollutant Emission Register (ER) (MNP, 2006a): results at a level of 5 * 5 km;
- Publications from LEI (Brouwer *et al.,* 2002; Hoogeveen *et al.,* 2008a; Luesink, 2012): national and regional results and;
- Overview of the Dutch research on ammonia emissions of the last 20 years (Starmans *et al.*, 2007).

Table 7.2 presents the Dutch ammonia emission from different sources over time as calculated with MAMBO and its predecessors up to 2004. The data presented in this table are the official ammonia emissions of the Netherlands as reported to the European Union. Later using different assumptions NEMA recalculated the national Figures and came to different Figures. Using the same assumptions as NEMA, MAMBO calculations yield identical results (Luesink *et al.,* 2012).

The emission of housing and storage is combined because manure is mainly stored indoors in the Netherlands and the emission factors of housing include indoor storage of manure. Only part of the manure is stored outside the animal houses, in the 80's this part was very small (almost no slurry and about 50% of the solid manure). At the end of the 90's about 50% of cattle manure, 20% of pig manure and almost all solid poultry manure were stored outside the animal house. Due to legislation, all these outside storages had to be covered, and this leads to an emission of 4 million kg of ammonia from outside storage, about 2.5% of the total ammonia emission in the Netherlands at that time.

Table 7.2: Ammonia emission from Dutch agriculture 1980 - 2004 (million kg of ammonia) (Luesink, 2004 and Hoogeveen et al., 2008a)

	1980	**1985**	**1990**	**1995**	**2000**	**2004**
Animal manure	204	227	210	166	128	111
Housing & storage	77	86	89	89	73	60
Grazing	14	16	16	14	10	9
Application	114	125	119	63	45	43
Fertilizer	15	12	13	13	11	9
Total agriculture	220	239	237	179	139	120
Emission per ha Agriculture area (kg NH_3)	107	118	110	90	71	62
Index (1980 =100)	100	110	108	81	63	55

Nowadays the national ammonia emission is half of the maximum value calculated in 1985. There are a couple of reasons why the ammonia emissions declined:

- Introduction and reduction of the milk quota caused a reduction in the number of dairy cattle from 4.2 million heads in 1985 to 2.6 million heads in 2004.
- Laws prescribing manure application techniques with low emission factors were implemented in 1988 at arable land and in 1991 at grassland. In 1995 they were fully implemented for all areas in the Netherlands.
- Buying of animal production rights by the government in 2001 and 2002 caused a decrease in the amount of pigs and poultry of about 15%.

The last few years the trend of a declining ammonia emission from agriculture has stabilized at around 120 million kg ammonia per year. The ammonia emission from non-agricultural sources in the Netherlands is about 13 million kg. Thus, the total ammonia emission in the Netherlands ranges from about 130 to 135 million kg in the last few years. This is almost the NEC target of 128 million kg in 2010 (MNP, 2006b).

As seen in Table 7.2, the ammonia emission from grazing animals slowly declines over the last few years. Besides the structural decline in the number of grazing animals it also originates from changes in the amount of nitrogen in fed roughage. Due to the Dutch manure laws (MINAS-system) the use of nitrogen fertilizer on grassland declined from more than 250 kg per hectare in 1998 to about 170 kg in 2002 and 2003, which led to a lower nitrogen content in on-farm produced roughage (Luesink and Wisman, 2005). The decline of ammonia emission would be even more when the grazing systems in the same period did not change from day and night grazing, to more limited grazing and summer feeding.

Figure 7.2 shows the Dutch ammonia emission from each area of a superimposed 5x5 km grid for the years 1980 and 2002. This Figure underlines the sharp decrease in ammonia emissions presented in Table 7.2. It also shows the contours of the three regions with high ammonia emissions, located in the south east, the central east and the central part of the Netherlands.

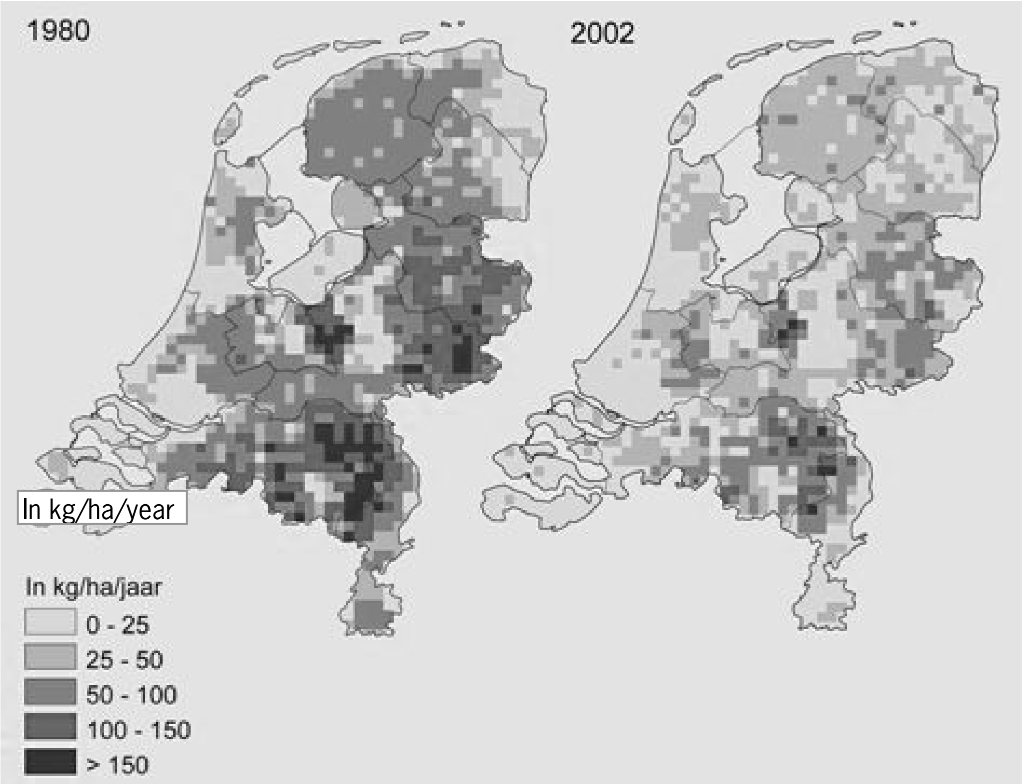


Figure 7.2: Ammonia emission in the Netherlands in kg per ha per year in 1980 and 2002 (RIVM/CBS, 2004).

As stated before as of 2011a national consensus model for national emissions of ammonia (NEMA) is in use (Velthof *et al*, 2009b). NEMA uses information from MAMBO since it cannot itself calculate application levels.

7.3.3 The yearly situation on the Dutch manure market

To establish the yearly situation on the Dutch manure market an expert group (CDM) has developed a protocol (Luesink *et al.,* 2006). Under supervision of this expert group, every year the manure streams are calculated with MAMBO in accordance with the protocol. In this section a summary of the results of 2006 are described (Luesink *et al.*, 2007). For other and more recent examples see (Luesink *et al.*, 2008b, 2009, 2010, 2011; De Koeijer *et al.,* 2011).

Figure 7.3 presents the results for the production of manure and Figure 7.4 shows the application of manure in the base scenario. The same Figures also display the results for a pessimistic and optimistic scenario. In the pessimistic scenario the conditions for the application of manure are negative in the optimistic scenario these conditions are good. The results for the production of nitrogen are similar to the results for phosphate (except for a level difference of factor 2.3), in this section only results for phosphate are displayed.

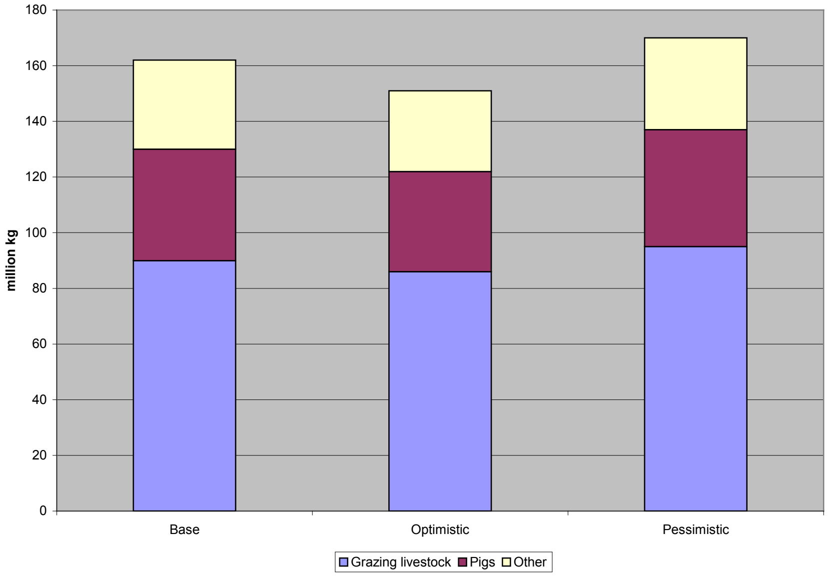


Figure 7.3: Manure production (kg of phosphate) for the year 2006 according to 3 scenario's (MA MBO calculations)

Production

For the year 2006 the phosphate production is calculated as 161 million kg. The band width of this estimate is 151 till 170 million kg (Figure 7.3). Grazing livestock are responsible for the largest part of the phosphate in manure from animals (55%). Pigs produce 25% of the phosphate and other animals 20%. Poultry is the main category in the group of other animals.

Application of manure

Figure 7.4 shows the application of manure. In the base scenario for 2006, 156 million kg phosphate is applied. In the optimistic scenario this is 6 million kg phosphate less because there is not enough manure to use all application possibilities. In the pessimistic scenario 153 million kg phosphate can be applied.

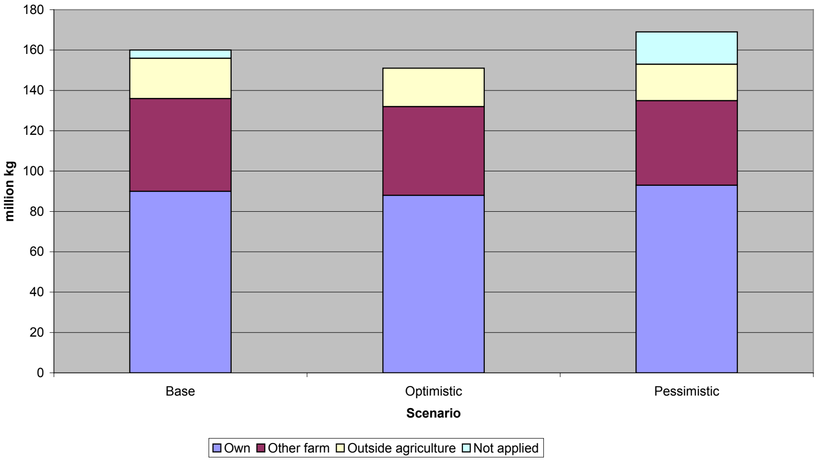


Figure 7.4: Application of manure (million kg of phosphate) for the year 2006 according to 3 scenario's (MAMBO calculations)

In all three scenarios the main part of the manure is applied at the farm where it is produced. In the base scenario this is 58%. 30% of the produced manure is applied at farms other then the farm where it is produced and 12% of the produced manure has a destiny outside of Dutch agriculture.

Non applied manure
Figure 7.4 also displays the part of the produced manure which cannot be applied. In the base scenario for 2006 this is 2,5% of the total production (4 million kg phosphate). In the optimistic scenario all the manure can be applied, in the pessimistic scenario 16 million kg (9.5% of the production) cannot be applied.

7.3.4 Results of the 2006 prediction of the Dutch manure situation 2009-2015

In 2006, new manure laws were introduced in the Netherlands. Application norms are an essential element of these new laws. From 2006 till 2015 the application norms will get more tight. In 2015, the application of phosphate in animal manure and artificial fertilizer should be in balance with the use of the crops it is applied on. The study described in this section was conducted on behalf of the ministry of Economic Affairs in order to establish the expected impact of these norms on the Dutch manure market in 2009, 2012 and 2015. The MAMBO model was used to calculate the impact. In this section some of the results are shortly presented.

Figure 7.5 displays the predictions of the production of phosphate for four different years. Figure 7.6 displays the total application of phosphate (from animal manure) for four different years. The results for nitrogen are in line with these results except for a level difference (application of nitrogen is a factor 2.3 higher). Figure 7.6 is based on the results of scenario 1.

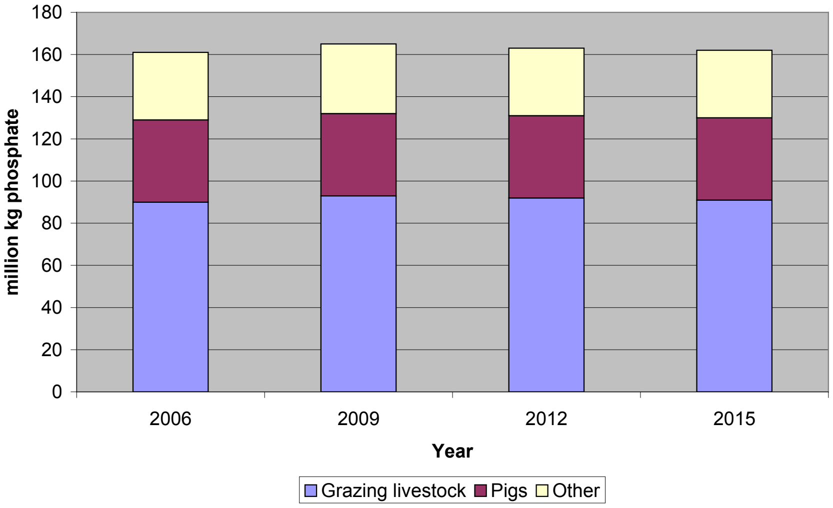


Figure 7.5: Estimated production of phosphate in 4 different years. Production (MAMBO calculations)

The estimated phosphate production for 2009 is slightly higher than for 2006 (Figure 7.5). This is due to the fact that the calculation for dairy and calving cows for 2009 is based on the firm specific values based on the milk productivity and the ureum content of milk, and the calculation for 2006 is based on the excretion values according to the WUM (base year 2004). The firm specific values result in a 5% higher value than the WUM values. In 2015, the phosphate production is more than 1% lower due to a decrease in the number of poultry and dairy animals.

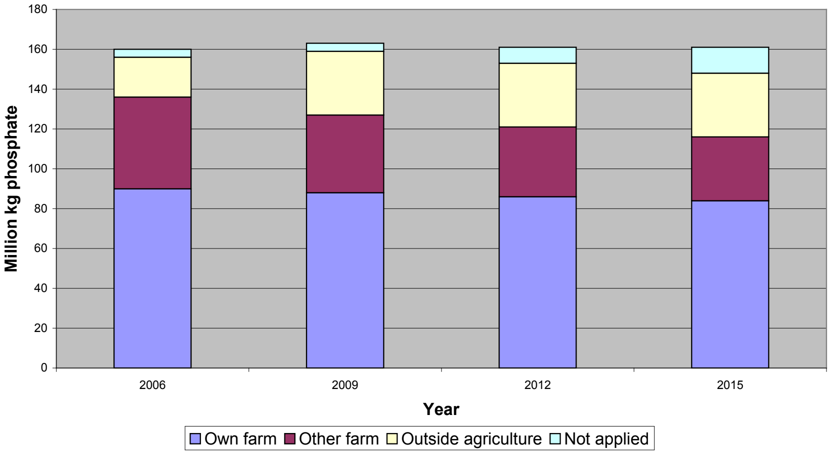


Figure 7.6 Estimated application of phosphate (for the year 2006, 2009, 2012, 2015) (MAMBO Calculations)

Application of manure

Due to the tightening of the application norms the amount of applied phosphate from manure decreases between 2006 and 2015 from 90 million kg till 84 million kg (Figure 7.6). Due to the lower acceptance of manure produced at other farms and the more tight application norms the application of manure from other farms is 7 million kg lower in 2009 then in 2006 (15% reduction).

The further tightening of the phosphate application norms after 2009 will result in a further decrease of 7 million kg of the application of manure produced on other farms. An increase in export (5 million kg) and the introduction of the manure incineration facility in Moerdijk will result in an increase of 12 million kg phosphate that is applied outside of Dutch agriculture.

Non applied manure

Figure 2 also displayes the amount of produced manure that cannot be applied. In 2006 as well as 2009, 2,5% of the production cannot be applied (4 million kg phosphate). This amount increases till 8% of the production for the year 2015 (13 million kg phosphate).

7.3.5 Soil loads with minerals

The STONE model (Beusen *et al.,* 2004) is used to calculate the amount of nitrogen and phosphate form agriculture that ends up in ground- and surface water in The Netherlands. An important input for these calculations is the amount of manure and fertilizer used at plot level. Since 1980 these data are calculated with the MAM/MAMBO model (Van der Ham *et al.,* 2007). In recent years, STONE uses these data on soil loads. Some results of the soil loads for the prediction of the nitrogen and phosphate content from 2006 to 2015 are presented below. Detailed results of this study can be found in Willems *et al.* (2007).

Figure 7.7 based on Table 7.3 combine 4 types of possible use of agricultural land (grassland; green maize; arable land and horticulture; agricultural land on part time farms (hobby farms)) and four scenarios (2006, 2009, 2015 variant 1 and 2015 variant 2). The numbers of the bars in Figure 7.7 refer to the following combinations of agricultural land use and scenario:

Table 7.3: Details of land use and scenario information related to Figure 7.7

Number	Use of agricultural land	Scenario
1	grassland	2006
2	grassland	2009
3	grassland	2015 v1
4	grassland	2015 v2
5	green maize	2006
6	green maize	2009
7	green maize	2015 v1
8	green maize	2015 v2
9	arable and horticulture	2006
10	arable and horticulture	2009
11	arable and horticulture	2015 v1
12	arable and horticulture	2015 v2
13	hobby farms	2006
14	hobby farms	2009
15	hobby farms	2015 v1
16	hobby farms	2015 v2

Averages of all soil

The sorting of the scenarios in the order of decreasing application of phosphate from animal manure in Figure 7.7 is just coincidence. The application of nitrogen from animal manure on grassland and hobby farms shows a decreasing trend. The application is in 2015 fifteen percent lower than in 2006. For arable crops (green maize, arable land and horticulture) the reduction of nitrogen from animal manure is substantial higher, around 25%.

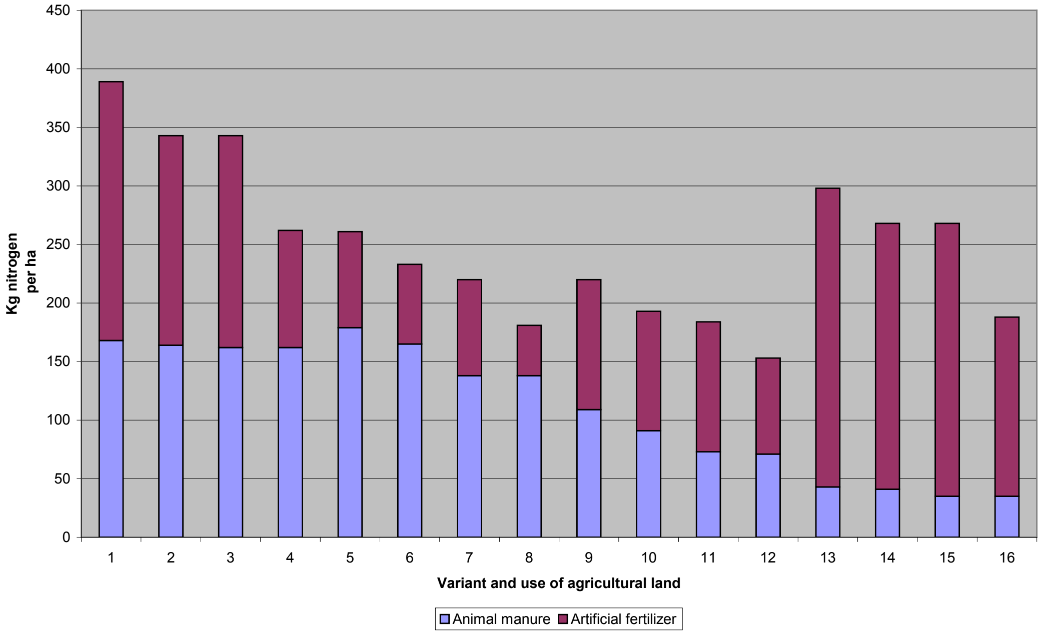


Figure 7.7: Maximum application of nitrogen (kg per ha) per use of agricultural land (column 1-4 grassland; kolom 5 – 8 green maize; kolom 9 – 12 arable land and horticulture; column 13- 16 hobby farms) within the nitrogen application norms. The variants in the order as displayed 2006, 2009, 2015v1 en 2015v2. (MAMBO calculations)

The large differences between the years and the variants are caused by the application of nitrogen from artificial fertilizer which can still be applied within the nitrogen application norms. These differences are especially relevant in the comparison of both variants for the year 2015. The tightening of the nitrogen application norm from 2009 till 2015 has a direct impact on the amount of artificial fertilizer that can still be applied (difference between variant 1 and 2).

The application of nitrogen from animal manure remains almost unchanged. The reason for this is that the application norm for phosphate is more restrictive in both variants. A tightening of the nitrogen application norm has therefore no direct impact on the possibilities for the application of manure.

Due to the fact that the application of animal manure is limited on hobby farms, there is much space for the application of fertilizer before the application norm is reached. It is not expected that the application space of 250 kg per ha is completely used in 2006, 2009 and 2005 (variant 1). According to the estimations the real application will be between 50 and 100 kg per ha. For grassland, the possible nitrogen application for fertilizer within the application norm will be around 200 kg per ha for the years 2006, 2009 and 2015 (variant 1). This is much higher than the current application of roughly 140 kg per ha (Hoogeveen *et al.,* 2008b). For green maize, arable land and horticulture the possibilities for the application of nitrogen from fertilizers are in line with the current application. In variant 2 for the year 2015, the possibilities for the application of nitrogen from fertilizers are much more limited for all crops (except for hobby farms) than the current application (around 35% lower).

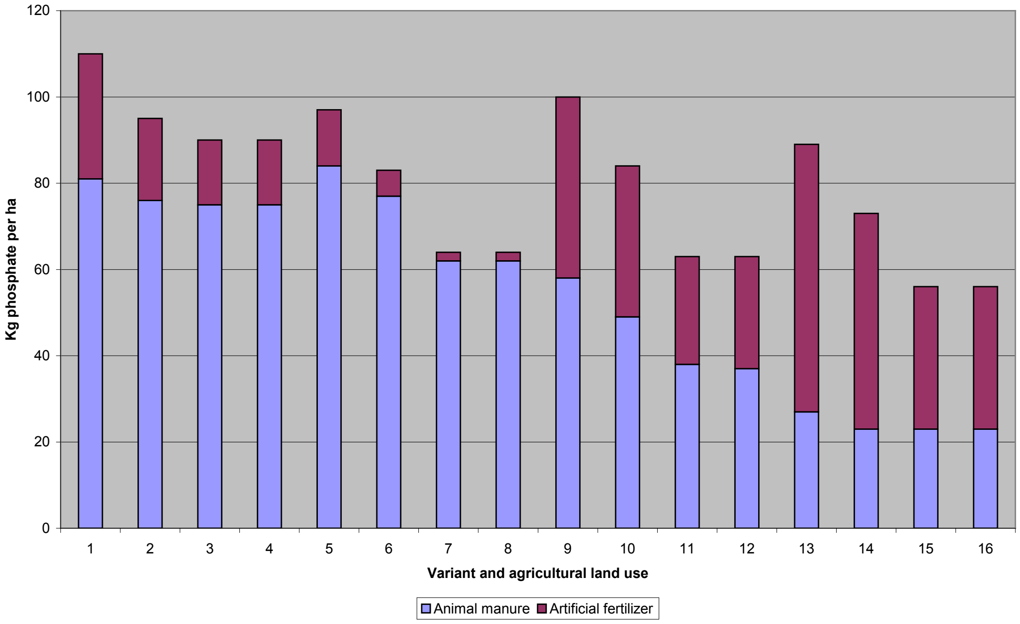


Figure 7.8: Maximum application of phosphate (kg per ha) per use of agricultural land (column 1-4 grassland; kolom 5 – 8 green maize; kolom 9 – 12 arable land and horticulture; column 13- 16 hobby farms) within the nitrogen application norms. The variants in the order as displayed 2006, 2009, 2015v1 en 2015v2. (MAMBO calculations)

The results for phosphate show a similar pattern (Figure 7.8). The application of phosphate from animal manure decrease to the same extent. The main difference is that the application opportunities for phosphate from artificial fertilizers are especially in the arable and horticultural sector and much less on grassland. Furthermore the supplementary phosphate application is much more limited than for nitrogen. Also for phosphate the application space for fertilizer in 2006 and 2009 is higher than the actual application. In 2015 the application space is 10% lower than the current application. There are however some differences between sectors, on grassland and on hobby farms the application space is still less than the current application of 10 to 15 kg per ha (Hoogeveen *et al.,* 2008b). In the arable and horticultural sector the current application of 40 to 50 kg per ha is much more than the 30 kg application space in 2015.

7.3.6 Calculating manure application taking into consideration P differentiation

As of 2010 the norms for phosphate fertilization depends on the phosphate state of the soils, see Table 7.4. MAMBO takes this into account in its calculations. And produces information on application of manure per crop soil type and soil quality class (see Figure 7.9 for an example). Farmers that do not test their soils fall into the highest soil phosphate state class. In the MAMBO calculations we differentiate between soils that have measured high states and high states because they haven't been measured.

Table 7.4: Phosphate application norms as of 2010 in kg Phosphate per ha Cropped area (2014 and 2015 are indicative)

Grass land

Phosphate state	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
High	90	90	85	85	85	80
Neutral	95	95	95	95	95	90
Low	100	100	100	100	100	100

Arable land

Phosphate state	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
High	75	70	65	60	55	50
Neutral	80	75	70	65	65	60
Low	85	80	75	70	70	70

Source: LNV, 2009

Figure 7.9: soil loads in kg per ha of minerals in manure using the 2010 P differentiation for selected cropclasses. (MAMBO calculations, Luesink and Kruseman, 2012): CRC1=winter wheat; CRC2=sugar beets; CRC3= consumption potatoes; CRC4=spring barley; CRC5=starch potatoes; CRC6=seed potatoes; CRC7=maiz; CRC8=summer wheat; CRC9=grass seed; CRC10=seed onions; CRC11=carrots; CRC12=beans; CRC13=cabbage. SQ1=unknown soil state; SQ2= high phosphate soil state (measured); SQ3= medium Phosphate soil state (measured); SQ4=low Phosphate soil state (measured).

7.4 Interaction of MAMBO with other models

7.4.1 MAMBO and STONE

The STONE system was developed for evaluating the effects of changes in the agricultural sector and in policy measures on the leaching of N and P to ground water and surface waters in the Netherlands. The system was in particular developed for evaluations at the national scale, and may also be applied at the regional scale. Its strengths are, in particular: (1) mechanistic description of soil processes; (2) detailed spatial schematization of rural areas in the Netherlands; (3) detailed information on applied manure and fertilizers and resulting N and P input into soils (Wolf *et al.,* 2003). The first version of STONE was released in 2000 and was then applied for the Fifth Environment Outlook. In the following years the spatial schematization (i.e. homogeneous spatial units with respect to soil type, hydrology, etc.) of the Netherlands was redesigned and new modules for calculating denitrification, crop's nutrient uptake and mineralization of organic matter were implemented.

At the current moment there is already a strong connection between MAMBO and STONE. MAMBO is used to calculate the soil loads and these output data are used in STONE to calculate the impact on ground and surface water. The calculation of soil loads is illustrated in Section 7.3.5. As of 2011 the input data for STONE are converted directly within the MAMBO framework from the schematization of MAMBO based on agricultural census to the schematization of STONE based on homogenous land units based on major land-use, soiltype, and water table using the common ground at municipality level.

7.4.2 MAMBO and Approxi

In forecast studies results of the APPROXI models can be used as inputs for MAMBO. The results of the APPROXI models who can be used are:

- Number of cows, heifers and calves per regional area;
- Average milk production per cow per regional area;
- The use of off-farm manure at cattle farms per regional area;
- The use of off-farm manure at arable farms per crop per regional area.

The results of MAMBO about manure prices are used as input in the APPROXI models.

7.4.3 MAMBO and DRAM

Dutch Regionalized Agricultural Model (DRAM) is a regionalized equilibrium model of the Dutch agricultural sector (Helming, 2005). The focus of this model is on market clearance and the impact of price changes on the economic and environmental performance of the Agricultural sector. The assumption is made that prices are determined by the supply and demand at a regional level. The model maximizes the total income from Agricultural activities within the economic and technical limitations. Regional price differences are determined by transportation cost form the exporting to the importing regions. DRAM is often used to estimate the economic effects of changes in the Common Agricultural Policy.

Output and input

The output of the model is information on the costs and revenues from agricultural activities and supply balances of fodder, young cattle, manure, land and quota. The model distinguishes regions based on differences in soil and agricultural specialization and covers the whole territory of the Netherlands. DRAM makes use from data from the Agricultural census and the Farm Accountancy Data Network.

Technique

DRAM is developed in GAMS. The user interface consists of the GAMS Simulation Environment (GSE). The calculations are, besides an optimisation routine, linear which ensures that the calculation speed is fast (less than 5 minutes to calculate results).

Connection with MAMBO

The strenght of DRAM in comparison to MAMBO is the market clearance which is explicitly modelled in DRAM. The strength of MAMBO is the level of detail and the calculation at individual farm level. This creates good opportunities to supplement each others' qualities. DRAM provides a range of opportunities to strenghten the economic component in MAMBO my explicitly modelling the market. The market clearance could be modeled within MAMBO or the models could be used simultaneously. The latter is especially interesting for the incorporation of all kind of dynamic effects. As described before, DRAM is often used to assess the impact of changes in the agricultural policy, translating these impacts into farm level effect creates the possibility to model the effects at a detailed regional level. This is especially important in project related to the water framework directive in which regional impacts are important.

This combination has been used in perspective scenario studies (Silvis *et al,* 2009)

7.4.4 MAMBO and Financial Economic Simulation Model

The financial economic simulation model is a model to evaluate the impact of policy measures and external developments on the financial economic situation of individual farms.

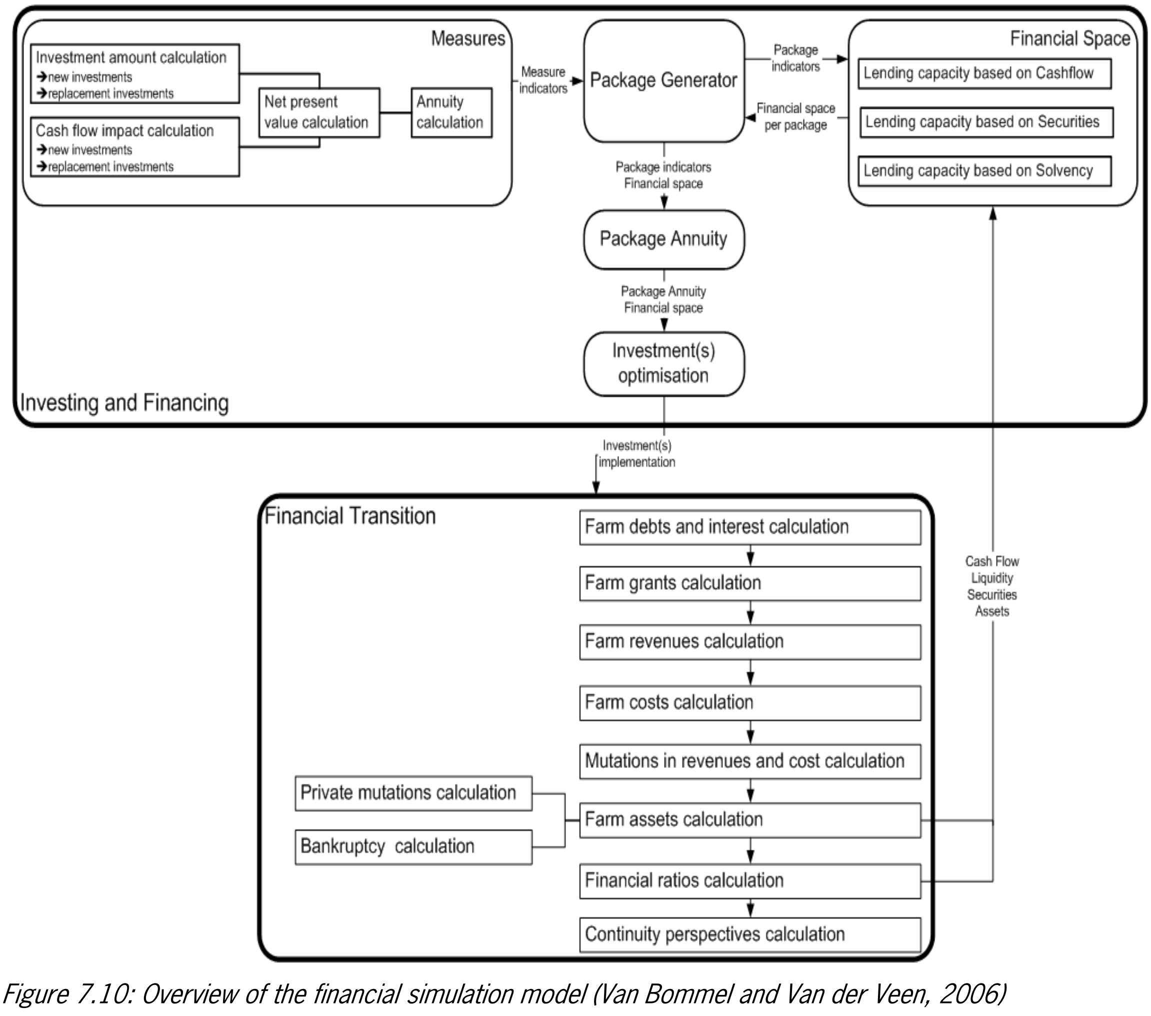


Figure 7.10: Overview of the financial simulation model (Van Bommel and Van der Veen, 2006)

The MICROWAVE FES-model is a micro-simulation model. The objective of the financial economic simulation model is to answer research questions about the continuity of agricultural and horticultural farms. Using this simulation model, continuity perspectives for a medium long period (5-10 years) of agricultural and horticultural farms can be determined. The financial economic simulation model consists of two major parts: the financial transition part and the investing and financing part as shown in Figure 7.10

In the financial transition modules we use the economic balance sheet, the profit and loss account, farm income, farm spending and investment decisions to calculate and describe the financial economic situation of each farm for each year. Good financial results will improve the liquidity position of the farm and bad results will worsen the farm liquidity.

Simulation of the future financial economic situation of a farm cannot be carried out without considering choices concerning investing in technically new assets, replacing old assets and other strategic measures such as changing the production plan. In the investing and financing module, the aim is to appraise different alternative measures and evaluate them against the background of the financial space available at the firm. Strategic choices, new investments as well as replacement investments can be considered. On the moment, the model only focuses on replacement investments. The Net Present Value and annuity are calculated for each package of replacement investments. Furthermore using financial indicators the financial space of each farm is calculated as the minimum of the lending capacity based on the cash flow, the securities and the solvency rate. The calculation of the financial space is based on Mulder (1994). Finally the investment decision of the farmer is simulated. From all packages that can be financed, using additional loans and free liquidity, the package with the highest annuity will be chosen and implemented.

Integration of both models would enable an integrated environmental economic evaluation of policy measures. For example new policy measures prescribing the use of low emission stables or a decrease of the animal could be evaluated both on their environmental impact as on the financial economic situation of the farm. This would not only allow the estimation of a first order impact of example a reduction of animals, but also the estimation of a second order impact due to the possible bankruptcy of farms.

8 Quality control

8.1 Introduction

This chapter describes the most important aspects of the quality control of the MAMBO model. Section 8.2 describes the software environment of MAMBO. This environment contains a set of tools for the structured development of the model and the use of the model. Section 8.3 describes the physical infrastructure of MAMBO. Section 8.4 till 8.7 will describe the tests, evaluations and sensitivity analyses that were performed to assess the quality and validity of the model.

8.2 Software environment

MAMBO has been developed in GAMS. GAMS is widely accepted in economic research as a high level language for a compact representation of large and complex models (McCarl *et al.*, 2012). GAMS started as software written by the World Bank and became very popular amongst economists and in the oil industry. GAMS is very strong in their mathematical notation of the model and the speed and quality of the different optimization packages (solvers). Without much GAMS knowledge people can read the model (i.e. GAMS looks very similar to the mathematical representation of the model).

GTREE

The GTREE model editor was used to develop the model. The GAMS programming language doesn't have a good editor that will clearly show the structure of the model. GTREE makes it easy to look into the details of the model, browse through the structure of the model and find declarations and usage of parameters, variables etc. Due to the fact that GTREE gives a clear representation of the model in a hierarchical structure, it increases the transparency and therefore the maintainability of the model.

MAMBO was developed using GTREE developed at LEI-Wageningen UR (Dol, 2006). GTREE is an integrated development environment which allows for a consistent development of modules with components.

QBGM

QBGM (Quality Based Generic Modeling) is a framework and a philosophy for constructing models (primarily used for GAMS models at LEI) based on the principles of strict separation of model code, run controls and data. MAMBO 2.x has been developed under QBGM.

Quality is becoming a major issue. Clients want it. For applied models used for policy analysis, policy makers want to be assured that the model results are robust and that both model and data meet certain quality standards.

For ISO certification procedures have been developed to ensure basic quality control, however the integration of these procedures into the practice of model building and application is not completely satisfactory. The model process and model quality management are usually two separate processes. QBGM is an attempt to bridge that gap.

QBGM should be user friendly in the sense that people using QBGM whether, model developers, model users, model reviewers, quality managers can work with it without undue effort. A certain level of *idiot-proof-ness* is very useful.

However it is not completely fool proof and care should be taken to ensure that the model has the quality it is supposed to have. This implies the use of well-defined protocols or standard operating procedures (SOPs).

Good modeling practices ensure
- Transparency of model and data processes; and
- Reproducibility of results.

For transparent and error free modeling it is imperative to follow a number of rules that fall under the heading of good modeling practice.

The first is the strict separation of model code and data. With model code we understand the declaration of items, the data manipulation rules, the calculation rules and the declaration and definition of optimization models. Model code consists of persistent concepts and their interrelationships. With data we understand, control variables that allow conditional compilation, the classifications of the sets used in the model (the set membership) the set declarations themselves were part of the model code. And finally any numerical data going into the model. Since we are dealing with mathematical models, numerical data are fundamental.

The second important issue of good modeling practice is the separation of model stages: model development, testing and application in projects. In line with this issue is the fact that for large and complex models there is usually a team that is involved in the process, so that roles are divided amongst the team members.

The third important issue is the division of the model code into handy blocks to allow a modular approach to model development and application. The modular approach consists of dividing a model into specific parts such as definition and declaration sections, blocks of related calculation rules, etc.. The modular approach also consists of separating out specific tasks to specific modules, where we define modules as separate smaller models that are related to other modules within a model framework. Using conditional compilation parts of models and components can be switched on and off.

The third important issue is the use of model specific error handling procedures. The error handling procedures are there to capture logical and data errors in otherwise perfectly legal code.

The fourth issue is that for error free modeling it is handy to use generic procedures to do certain general tasks. The tasks that warrant the use of generic procedures are those tasks that ether (1) occur frequently, (2) are complicated (from a modeling perspective) or (3) are prone to difficult to trace errors, or a combination of these. Generic procedures can be tested separately and ensures the user of these procedures that that piece of code is good.

Combination of tools

While GAMS is the main piece of software within the modeling framework, there are a few other pieces of software that are indispensable. WLOG is a small program that provides a window into the model while it is running (Kalvelagen, 2006). It is used to monitor progress, send important messages to the user and report errors as they occur. Within the framework of MAMBO data management is important. The data that is used in the GAMS models has to be prepared so that it is in a format that GAMS can use and simultaneously meets the standards of excellence required of the model. The process of data management is also embedded in generic GAMS modules that guarantee uniform procedures for data preparation. In the conversion of different data formats into the GDX (GAMS Data eXchange) format that we use as standard input several conversion programs are used: GDXXRW for conversion from Microsoft EXCEL workbooks (GAMS, 2006), and the data manipulation language AWK (Robbins, 2004) for converting text files into GDX files. The combination of different tools is highlighted in Figure 8.1.

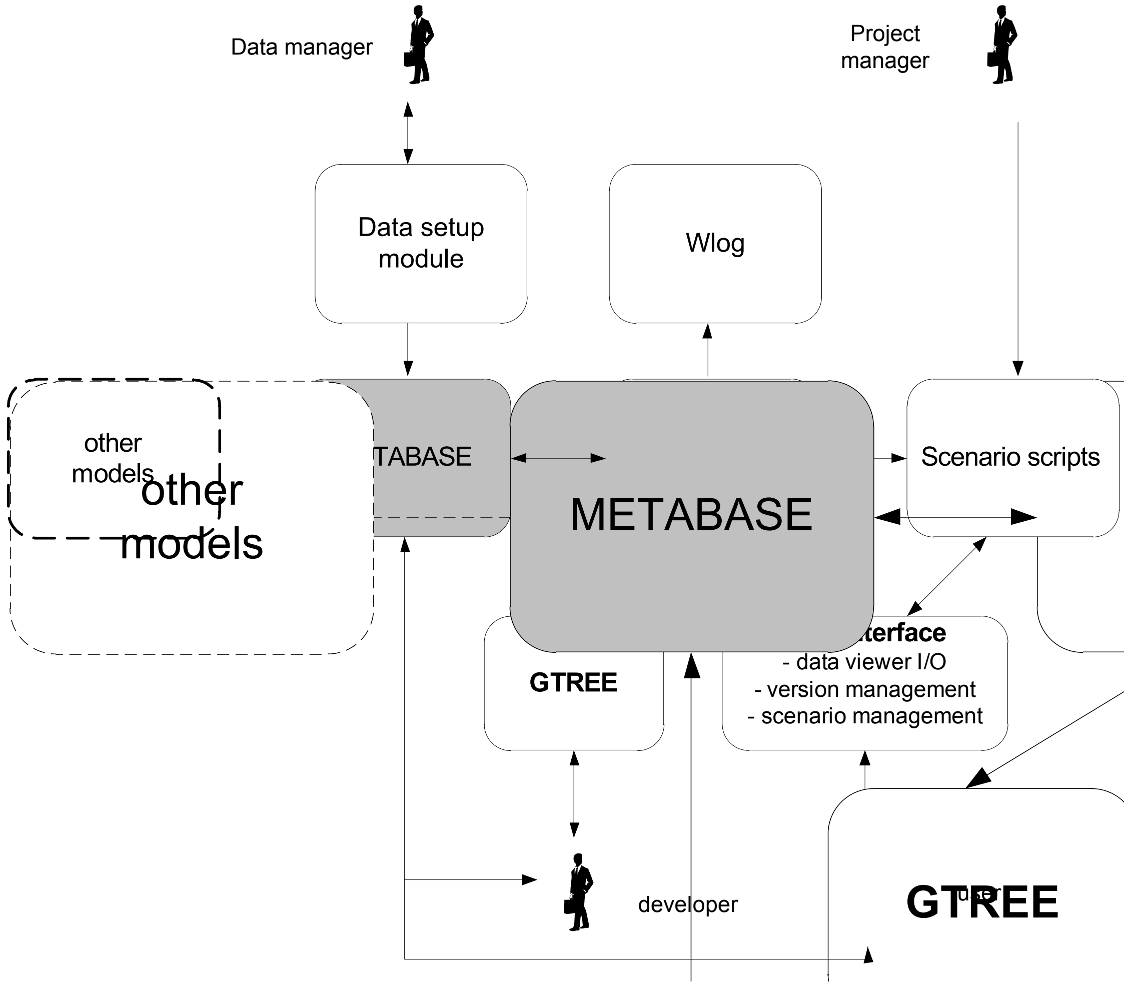


Figure 8.1: Tools for the development and use of MAMBO

User interface

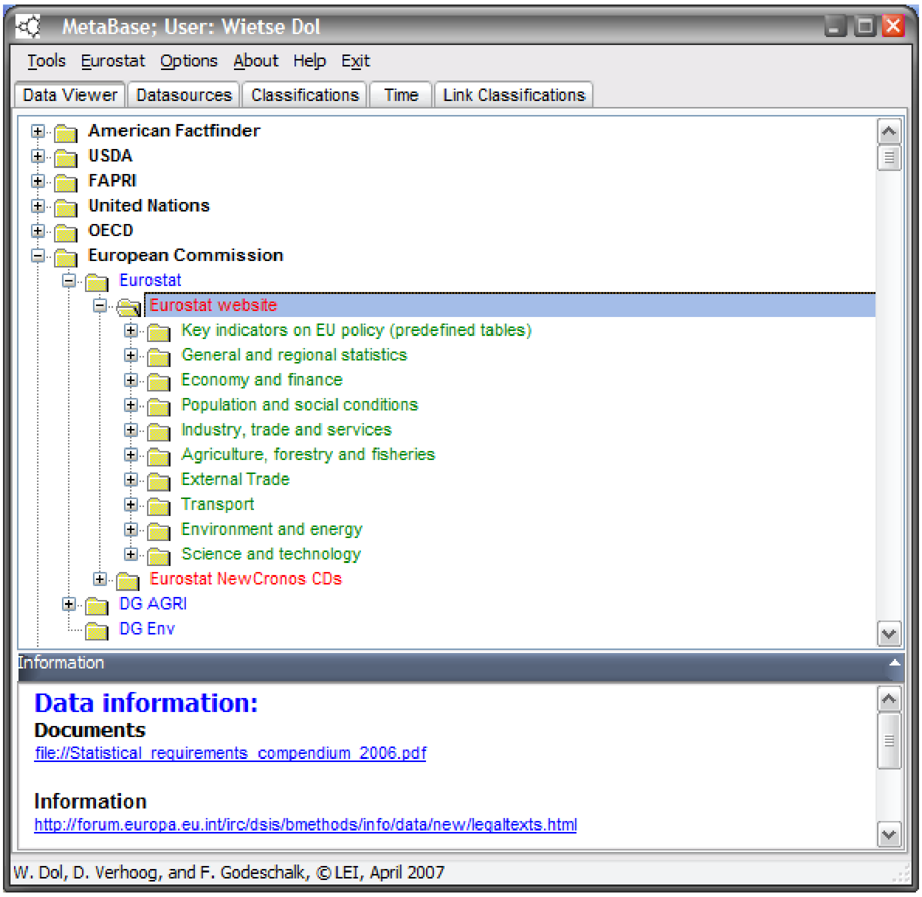
Several tools are available at LEI to run models, and to present the results (e.g. GSE: Dol, 2004). Furthermore GSE can be used in formulating and running different scenarios and in defining various versions of the model. GSE itself will take care of the configuration management task of preserving the various versions and scenarios. This guarantees reproducibility of results; also scenario comparison is made possible within the GSE-environment.

Main advantages of GSE:

- Model input/output viewer
- Model version control, all sources are stored in a database
- Scenario inheritance (ease of use and keep database small)
- Add documents/model knowledge to model version and scenario
- Scenario comparison (over all model versions & scenarios)
- Multidimensional viewer
- Output: Printer, HTML, Excel, Graph etc.

Metabase

For research, good data is an essential starting point. Many institutes spend many person-years on collecting and storing secondary data. Model builders are not an exception, they spend much effort on getting the correct model data and updating it. Keeping the data up to date is essential to be worthwhile for policy scenarios. Many data suppliers use their own way of presenting their data and making it available for the public. Since all these ways differ, research institutes spend a lot of time on collecting the correct data. Using data from different sources (combining them or even better harmonising, completing and make consistent) is hardly done because of the effort it takes and the lack of good software. Metabase integrates the definition, storage and management of data items. This facilitates the quality control, but also the re-use of data because of the uniform definitions of data and the explicit relationship between different data items. It can therefore stimulate the use of correct data and the re-use of the data in research and hence improve data efficiency and quality in research (Figure 8.2).



- American Factfinder
- USDA
- FAPRI
- United Nations
- OECD
- European Commission
  - Eurostat
    - Eurostat website
      - Key indicators on EU policy (predefined tables)
      - General and regional statistics
      - Economy and finance
      - Population and social conditions
      - Industry, trade and services
      - Agriculture, forestry and fisheries
      - External Trade
      - Transport
      - Environment and energy
      - Science and technology
    - Eurostat NewCronos CDs
  - DG AGRI
  - DG Env

Data information:

Documents

file://Statistical_requirements_compendium_2006.pdf

Information

http://forum.europa.eu.int/irc/dsis/bmethods/info/data/new/legaltexts.html

W. Dol, D. Verhoog, and F. Godeschalk, © LEI, April 2007

Figure 8.2: Interface of metabase

Data explorer

An essential element of GSE is the data explorer. The data explorer allows the inspection of input and output variables, furthermore the values of input variables can be set for specific scenarios. Some important menu options of the Data explorer are:

- *HTML output:* will popup the HTML output window;
- *Graph:* will open the Graph output window';
- *Print:* will show the Print preview window;
- Save as: will offer you to save the grid to Word, Excel, ASCII, HTML, or CSV;
- *Save data:* When you are allowed to change data (input parameters only and only when the scenario is not write protected) and when you have changed some value, the *Save data* option will be enabled and you can press this button to save the changes to the database.

Data from the DataExplorer can also be used as input for GIS applications. See Figure 8.3 for a typical example using the GIS viewer that is related to the DATAexplorer.

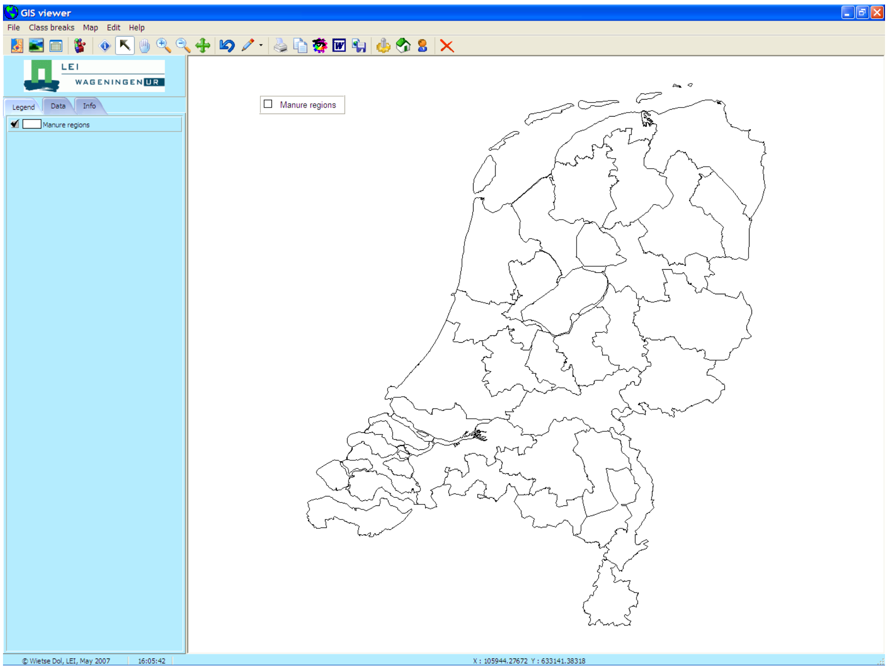


Figure 8.3 GIS viewer with layout of 31 manure regions in the Netherlands

8.3 Model server

The model runs at a central model server. This provides a range of advantages:
- Central location for models, scenarios and results;
- Backup procedure for model results;
- Access to model scenarios for all people involved in a project;
- Accessibility of (previous) model runs for all authorized people.

In short, it guarantees sharing of knowledge around model versions, scenarios and outputs in inputs. This strongly increases the transparency and the reproducibility of (policy) applications.

The model code is versioned using Tortoise SVN which has the advantage of complete back-up of all old versions of the model with memos on the changes that have been implemented.

8.4 MAMBO output test procedure

To assure the quality of the output, working procedures and evaluation points have been defined (Luesink, 2010). There are two essential elements in this procedure. (1) to make sure that the underlying assumptions for a scenario are well implemented before the model is run and (2) to check whether outputs are consistent with expectations and other model runs.

8.4.1 General output evaluation points

While using MAMBO, there are general evaluation points in which the user checks the output of the different modules. At the same time the user can check some input data like for instance animal numbers per regional area, animal numbers per animal class, crop area per regional area etc.. This enables the user to evaluate the current run and the user can make an assessment about the final results of the modules or model.

To test whether the input data or module output is consistent with the expectations of the user, the following output is of use:

- Mineral production;
- Surplus production;
- Transported manure;
- Exported manure;
- Processed manure;
- Storage manure.

Mineral production

In the module MAMBOBMPC the basic manure production calculations find place. In the module output the user can check en test the animal numbers in BasicCheckSums. This information is of importance in order to test whether the mineral production generated by the model is in consistence whit the users expectation or previous years.

Surplus production

The surplus production is calculated in the Rule-based Firm Model. The surplus production is the surplus in kilogram manure that cannot be applied at the own firm. It gives the user an indication whether the application of the manure at the own firm contains no errors in for instance input data or input from other modules.

Transported, exported, processed and stored manure

Manure that cannot be place on the own fields can be transported to other firms, exported from the agricultural sector, processed and stored (if user defined this in the model settings). In the Transport model (a spatial equilibrium model for distribution of surplus manure) the previous output is generated. The volume of transported manure provides an insight in the manure application on other agricultural firms, hobby firms and non agric soils. The remaining manure is either exported, processed or ends in the storage. The volume of exported and processed manure has to be the same as defined in the input data, except when there is simply not enough manure to export of process.

8.4.2 Scenario specific output evaluation points

When expectations or assumptions of future developments in for instance animal numbers or excretion are taken into account, a certain uncertainty exists about the original input data. A user can perform a sensitivity analysis of a model run in order to test the sensitivity of the model input on the model output.

MAMBO has the opportunity to cope with uncertainty by changing input data with user defined factors. The following input data can be changed in order to explore future developments or to perform a sensitivity analysis of a model run:

- Animal numbers;
- Crop area;
- Fertilizer mineral content;
- Fixed fertilizer mineral content;
- Minimal fertilizer application;
- Urea and milk production;
- Manure export;
- Manure process.

In the module DataChange the changes of the input data are executed. The output of this model gives an overview of all the changes made per input data. This way the user can simply check whether the changes in data are well implemented and if the following modules will use correct data inputs, for example the calculation of the mineral production in MAMBOBMPC. Procedure for testing module output.

During the development of MAMBO the separate modules and module changes are tested on the basis of the generated output of these modules. In the previous sections the evaluation points are discussed. This section addresses the procedures used to test runs and different variants of runs.

Step 1 Basic assumptions are made for every model run. The user has to check the implementation of these assumptions before the model starts.
Step 2 Start running the model after all input data is checked on existence.
Step 3 If applicable, the output of DataChange is checked/tested whether the changes in the input data are implemented.
Step 4 When the module MAMBOAMPC is reached the output of MAMBOBMPC is evaluated whether the outcome of the mineral production is in line with the output of expectations and other model runs.
Step 5 The output of the Rule-based Firm Model is evaluated based on consistency with other runs and expert judgment.
Step 6 The output of the Transport Model is evaluated to test whether the assumptions are correctly implemented in the model and whether results are consistent with other model runs. The exported and processed manure totals have to be the same as defined in the basic assumptions. Any discrepancies between the assumptions and the total exported and processed manure meant that there was simply not enough manure or the model contained an error.

Appendix 2 gives an illustration of the consistency checks. For each model run a directory is created with all essential files. The model run is evaluated against another model run.

8.5 Comparison results of MAMBO and MAM

In this section a comparison is made between the results of MAMBO and its' predecessor MAM. One of the goals was to have a backward compatible model in order to be able to perform calculations in line with the previous studies. Therefore the model runs of MAMBO that are presented in this section are performed on the same level of aggregation as the calculations in MAM. This section presents results for the mineral production, the stable emission and the storage emissions for the manure regions with the highest manure production.

8.5.1 Mineral production

Table 8.1 presents the nitrogen and phosphate production for the manure regions with the highest production. The table shows that the difference of the mineral production in the regions between MAM and MAMBO is less than 1% and in most cases less than 0.1%.

Table 8.1: Mineral production and difference in mineral production between MAM and MAMBO for the 15 manure regions with the highest productions (1000 kg N).

	Nitrogen (x1000 kg)			**Phosphate (x1000 kg)**		
Manure region	**MAM**	**MAMBO**	**Difference (%)**	**MAM**	**MAMBO**	**Difference (%)**
Sall. Twente e.o.	43714	43692	*100.1*	15449	15456	*100.0*
Peel land van Cuyk	35771	35786	*100.0*	14378	14388	*99.9*
Achterhoek	35654	35646	*100.0*	12670	12677	*99.9*
Maask Meijerij	32955	32994	*99.9*	12681	12699	*99.9*
Westnoord Limburg	24499	24514	*99.9*	10592	10598	*99.9*
Zuidwest Friesland	24282	24352	*99.7*	7519	7538	*99.8*
De Wouden	23871	23945	*99.7*	7629	7650	*99.7*
Groningen	22925	22995	*99.7*	7498	7517	*99.7*
Noord Overijssel	21985	22017	*99.9*	7477	7494	*99.8*
Drenthe excl. Veenk.	21350	21397	*99.8*	7015	7026	*99.8*
Zuid-Holland excl. Zeeklei	21024	21129	*99.5*	6635	6662	*99.6*
West Veluwe	20845	20862	*99.9*	8615	8622	*99.9*
Betuwe e.o.	17388	17406	*99.9*	6298	6309	*99.8*
Noord Noord-Holland	16519	16613	*99.4*	5101	5128	*99.5*
West Kempen	14961	14957	*100.0*	5445	5447	*100.0*

Table 8.2 presents the nitrogen and phosphate production per manure category. The overall difference is 0.2%. For grazing beef cattle there is a difference of almost 2 percent. This difference will be further analyzed in the future.

Table 8.2: Mineral production and difference in mineral production between MAM and MAMBO per manure category.

	Nitrogen (x1000 kg)			**Phosphate (x1000 kg)**		
Manure region	**MAM**	**MAMBO**	**Difference (%)**	**MAM**	**MAMBO**	**Difference (%)**
Dairy cattle	187,310	187,594	*99.8*	61,291	61,381	*99.9*
Young dairy cattle	76,944	76,946	*100.0*	20,342	20,401	*99.7*
Grazing beef cattle	33,321	33,956	*98.1*	9,525	9,697	*98.2*
Non grazing beef cattle	9,165	9,167	*100.0*	3,083	3,083	*100.0*
Fattening calves	11,507	11,506	*100.0*	4,472	4,473	*100.0*
Fattening pigs	65,417	65,415	*100.0*	25,164	25,160	*100.0*
Sows	34,385	34,381	*100.0*	15,656	15,659	*100.0*
Laying hen	32,310	32,301	*100.0*	19,387	19,380	*100.0*
Broilers	32,357	32,356	*100.0*	12,580	12,583	*100.0*
Total	482,716	483,622	*99.8*	171,500	171,817	*99.8*

8.5.2 Stable emission

Table 8.3 presents the stable emission for the 15 regions with the highest production. Per region the stable emission for MAMBO and MAM are almost the same. The difference between the two models is minimal.

Table 8.3: Stable emission and difference in stable emission between MAM and MAMBO for the 15 manure regions with the highest productions (1000 kg N)

Manure region	**MAM**	**MAMBO**	**Difference (%)**
Salland Twente e.o.	4446	4459	99.7
Peel Land van Cuyk	5024	5019	100.1
Achterhoek	3695	3710	99.6
Maaskant Meijerij	4104	4098	100.1
West Noord-Limburg	3139	3132	100.2
Zuidwest-Friesland	1708	1709	99.9
De Wouden	1780	1781	99.9
Groningen	1885	1879	100.3
Noord-Overijssel	1952	1963	99.4
Drenthe excl. Veenkoloniën	1717	1710	100.4
Zuid-Holland excl. Zeeklei	1574	1573	100.1
West-Veluwe	2589	2587	100.1
Betuwe e.o.	1689	1691	99.8
Noord Noord-Holland	1093	1089	100.3
West-Kempen	1698	1699	99.9

8.5.3 Storage emission

Table 8.4 presents the storage emission per manure region for the 15 manure regions with the highest production. For most regions the differences are very limited.

Table 8.4: Storage emission and difference in storage emission between MAM and MAMBO for the 15 manure regions with the highest productions (1000 kg N)

Manure region	**MAM**	**MAMBO**	**Difference (%)**
Salland Twente e.o.	261	262	99.4
Peel Land van Cuyk	350	350	99.9
Achterhoek	219	220	99.4
Maaskant Meijerij	261	262	99.8
West Noord-Limburg	380	380	100.0
Zuidwest-Friesland	115	115	99.9
De Wouden	137	137	100.0
Groningen	162	162	100.1
Noord-Overijssel	134	135	99.2
Drenthe excl. Veenkoloniën	139	139	100.1
Zuid-Holland excl. Zeeklei	98	98	100.0
West-Veluwe	246	246	99.9
Betuwe e.o.	151	151	99.6
Noord Noord-Holland	79	79	100.1
West-Kempen	92	92	99.6

Overall the outputs of MAMBO are very similar to the output of MAM. Differences in the level of precision in performing the calculations can easily result in small differences in results.

8.6 Sensitivity and uncertainty analysis

Besides the tests described in the previous section a number of sensitivity analysis were performed. Sensitivity analysis is the study of how model output varies with changes in model inputs. A model is sensitive to an input if changing the value of that input variable changes the value of the output variables.

In different studies the effect of uncertainties of the input parameters on the results of production and application are calculated. This section gives a short description of the uncertainties as studied in the yearly monitoring of the manure market (Luesink *et al.,* 2008b). Sections 8.4.1 till 8.4.6 describe import inputs of the model and the uncertainties that are taken into account in the analysis. Sections 8.4.8 and 8.4.9 present the consequences of these uncertainties on the important output variables of the model.

8.6.1 Number of animals

To take into account other statistics (Hubeek *et al.,* 2004 and LNV-DR, 2006), alternative numbers of animals are considered for the following groups (in percentage of change in comparison to the expected situation):

- 15% less broilers;
- 7% less laying hens;
- 8% less beef and;
- 100% more sheep, horses and ponys.

8.6.2 Excretion of nitrogen and phosphate

Different studies (Tamminga *et al.*, 2004 and Jongbloed *et al.,* 2005) describe uncertainties in the excretion of nitrogen an phosphate of animals. Table 8.5 given a summary of the uncertainties.

Table 8.5: Uncertainty borders of N- en P2O5 excretion per animal category (Bron: milkcows, Tamminga et al., 2004; pigs and poultry, Jongbloed et al., 2005).

Animal category	**Index uncertainty**			
	borders nitrogen		**borders phosphate**	
	upper bound	*lower bound*	*upper bound*	*lower bound*
Milkcows	110.0	95.0	110.0	95.0
Fattening pigs	106.0	93.1	118.7	81.3
Sows	106.4	93.3	114.9	85.1
Laying hens	106.5	93.4	113.5	86.5
Broilers	106.1	93.4	120.6	79.5
All other animals	100.0	100.0	100.0	100.0

8.6.3 Number of farms with derogations

It is not sure how many farms will apply for and be eligible for derogation. From 21,220 farms it is sure that they will get derogation. For 1500 farms it is uncertain. In the base situation it is calculated that all 22,720 farms make use of derogation (nitrogen norm for ruminants nitrogen of 250 kg pro hectare). In the uncertainty analysis we assume that 1500 farms cannot use derogation (nitrogen norm for ruminants nitrogen of 170 kg pro hectare).

8.6.4 Acceptation degree of off-farm manure

The uncertainties in the amount of off-farm manure applied on grassland and silage maize is studied by Staalduinen *et al.* (2002). The results of Staalduinen *et al.* (2002) are used as the boundaries of the acceptation degrees on grassland and silage maize:

1. Non derogation farms have an acceptation degree for off-farm manure from 10 percent points higher till 10 percent point lower than the expected situation;
2. Derogation farms have an acceptation degree for off-farm manure from 20 percent points higher till 20 percent point lower than the expected situation at grassland;
3. All farms have an acceptation degree for off-farm manure from 10 percent points higher (with a maximum of 100%) till 10 percent points lower than the expected situation on silage maize.

In 2006 two reports (Hoogeveen *et al.,* 2008b and Van Dijk *et al.*, 2007) described the acceptation of off-farm manure at arable farms. The results of those studies are also translated into uncertainties in the use of off-farm manure. The results are:

- At sandy soils margins of 5 percent points higher and lower acceptation degrees are considered;
- At other soils a lower margin of 5 percent points and an upper margin of 10 percent points are considered.

8.6.5 Minimum artificial fertilizer gifts

The margins of the minimum fertilizer gifts are based on the knowledge of manure application experts (Dekker, 2000). The borders as considered in the calculations are given in table 8.6.

Table 8.6: Uncertainty borders of the minimum artificial fertilizer gifts in kg per ha per crop class

Crop class	**Borders**		
	Expected	*Upper*	*Lower*
Nitrogen			
- Potatoes, bulbs and vegetables	60	80	40
- Beets and seed potatoes	40	60	20
- Winter wheat	50	70	30
- trading crops and wood production	30	50	10
- fallow land	0	0	0
- other arable crops	20	40	0
Phosphate			
- potatoes, bulbs and vegetables	0	20	0
- beets and seed potatoes	0	20	0
- winter wheat	0	20	0
- trading crops and wood production	0	20	0
- fallow land	0	0	0
- other arable crops	0	20	0

8.6.6 Application outside Dutch agriculture

Due to the high pressure on the manure market in 2006, it is considered that the lower border of export and processing is the expected one and the higher border is 19% more processing and 29% more export than what is expect.

The borders of application of manure at natural grassland, on land from private persons and hobby-farms are 25% lower end 10% higher than in the expected situation.

The names of the variants to calculate the results of the uncertainties are given in Table 8.7.

Table 8.7: Variant names of the variant for to calculate the results of the uncertainties of the input parameters from MAMBO

Parameter	**Borders**	
	Upper	*Lower*
Number of animals	Animals high	Animals low
Excretion	Excretion high	Excretion low
Number of derogation farms	Not applicable	Less derogation farms
Acceptation off-farm manure	High acceptation	Low acceptation
Artificial fertilizer use	High artificial fertilizer gifts	Low artificial fertilizer gifts
Application outside Dutch agriculture	High application outside Dutch agriculture	Low application outside Dutch agriculture

8.6.7 Results of uncertainty analysis for nitrogen and phosphate production

For four variants of the uncertainty analyses the difference in production compared to the base scenario are given in Table 8.8.

Table 8.8: Nitrogen and phosphate production by the variants for the uncertainty analyses in The Netherlands in 2006 in million kg

Description	**Variants**				
	Base	*Excretion high*	*Excretion low*	*Animals high*	*Animals low*
Nitrogen					
- Dairy	215	231	207.6	215.3	215.3
- Beef and horses	32	32	32.0	43.3	30.5
- Fattening calves	9	9	9.1	9.1	8.4
- Fattening pigs	50	54	45.2	49.7	46.7
- Sows	24	26	22.1	24.3	22.8
- Poultry	36	39	32.7	36.0	32.4
Total	366	391	348.7	377.7	356.1
Phosphate					
- Dairy	74.9	80.4	72.2	74.9	74.9
- Beef and horses	14.8	14.8	14.8	21.1	14.1
- Fattening calves	4.6	4.6	4.6	4.6	4.3
- Fattening pigs	24.2	28.8	19.7	24.2	22.8
- Sows	15.3	17.6	13.0	15.3	14.4
- Poultry	27.3	31.1	23.4	27.3	24.9
Total	161.1	177.3	147.7	167.4	155.4

Taking into account the uncertainties about the excretion values, there will be an animal nitrogen production in The Netherlands in 2006 between 349 and 391 million kg with an expected value of 366 million kg. For phosphate the bandwidth is 148 up to 177 million kg with an expected production of 161 million kg.

The uncertainties about the number of animals result in a bandwidth of nitrogen production of 356 up to 378 million kg and for phosphate the bandwidth is between 155 and 167 million kg.

8.6.8 Results of uncertainty analysis for application of manure

Influence manure production

In the variants with a higher manure production (higher excretion values and higher number of animals) more manure is placed on the own farm (4 million kg of phosphate and 6 – 8 million kg of nitrogen) and less at other farms (2 million kg of phosphate and 0-6 million kg of nitrogen).

In the variants with a lower manure production, the nitrogen and phosphate application at own and at other farms is 2 till 5 million kg lower than in the base situation (Table 5.5). The conclusion that the application of off-farm manure is lower than in the base situation can be explained by the fact that there is not enough off-farm manure to fill up all potential application room.

Influence number of derogation farms

Excluding the 1500 farms, for which it is not sure that they make use of derogation, from the application norms of derogation, the amount of manure that can be placed is 2 million kg of nitrogen and 1 million kg of phosphate lower then in the base situation (Table 8.9).

Table 8.9: Results manure application in 2006 by uncertainty's of number of animals excretion and number of derogation farms in million kg

Description		**Variants**				
	Base	*Excretion high*	*Excretion low*	*Animals high*	*Animals low*	*Dero-*[1)]
Nitrogen						
- Own farm	245	253	241	251	244	243
- Other farms	79	73	75	79	75	80
- Hobby-farms	7	7	7	7	6	7
- Export	28	30	27	28	28	28
Total	359	363	349	365	353	357
Phosphate						
- Own farm	90	94	88	94	90	89
- Other farms	46	44	41	45	45	46
- Hobby-farms	4	4	4	4	4	4
- Export	16	18	14	16	16	16
Total	156	160	147	159	155	155

[1)] Dero- = less derogation farms

Influence artificial fertilizer

The variant with a lower use of artificial fertilizer has no influence on the application of manure, because the nitrogen norms are not the limiting factor in the application of manure. In the variant with high artificial fertilizer application, the amount of off-farm animal manure is 8 million kg of nitrogen and 5 million kg of phosphate less than in the base situation (Table 8.10).

Impact of acceptation degree on off-farm manure

The acceptation degree is the maximum amount of off-farm manure that farmers will accept. In the variant with low acceptation degrees the amount of manure that is placed is 9 million kg of nitrogen and 7 million kg of phosphate less than in the base situation. The variant with high acceptation degrees results in the application of 4 million kg of nitrogen and phosphate more than in the base situation. This could be even more, not all room for off-farm manure is used, through a lack of off-farm manure.

Impact of application outside Dutch agriculture

In case of less application outside of Dutch agriculture, the total application of manure is 2 million kg of phosphate and 3 million kg of nitrogen less than in the base situation. In case of a high application outside of Dutch agriculture, the application of manure is 4 million kg of phosphate and nitrogen higher than in the base situation.

Table 8.10: Results manure application in 2006 by uncertainty's of acceptation off-farm manure, use of artificial fertilizer and application outside Dutch agriculture in million kg

Description		**Variants**					
	Base	*High acceptation*	*Low acceptation*	*High artificial fertilizer*	*Low artificial fertilizer*	*High application outside Dutch*	*Low application outside Dutch*
Nitrogen							
- Own farm	245	245	245	243	245	245	245
- Other farms	79	82	70	74	79	77	82
- Hobby farms	7	8	3	7	7	7	5
- Export	28	28	28	28	28	33	25
Total	359	363	347	351	359	363	356
Phosphate							
- Own farm	90	90	90	89	90	90	90
- Other farms	46	49	40	42	46	46	46
- Hobby farms	4	5	2	4	4	4	3
- Export	16	16	16	16	16	19	15
Total	156	160	148	151	156	160	154

8.7 Validation and calibration of MAM/MAMBO

To guarantee an accurate result, models need to be validated and calibrated. Over the years, MAM calculated emissions have been validated by measurements in the field (Oudendag, 1999; Smits *et al.*, 2005). It was concluded that emission differences fell within expected margins. However, it was revealed that MAM was sensitive for the level at which housing data was provided. With housing data input at regional level, the ammonia emission was underestimated 15%. This problem was solved by providing these data on farm level. The difference between calculated and measured emission values proved to be less than 1%. It was also concluded that similar to the housing data, also the data on manure spreading and farm area location should be known at farm level.

In 1999 a group of Dutch scientists reviewed the calculation rules and the principles of the calculation of the ammonia emission with MAM (Steenvoorden *et al.*, 1999). They made a couple of recommendations to improve the calculation of the ammonia emission. Most of the recommendations addressed the principles and the available data, not on the calculation rules. In 2004, it was concluded that most of these recommendations were implemented in the calculation methods of the Dutch national ammonia emission inventory (De Mol, 2004). With MAMBO all the recommendations of Steenvoorden *et al.* (1999) and De Mol (2004) on the calculation rules and the principles of the calculation of the ammonia emission are implemented.

Each year, the manure distribution algorithm of MAM is calibrated with statistical data on the transport of manure (Luesink, 2002). As a result of the actual manure laws, each transport needs a certificate, which is registered to facilitate supervision of the execution of these laws. CBS provides the statistical data on these manure transports to LEI.

In 2006 the international EAGER group (A core group of emission inventory experts) compared six models that are used for the national agricultural ammonia emission inventories in Europe with each other (Reidy *et al.,* 2007). One of these models was the MAM-model. The results showed a very good agreement among models, indicating that the underlying N flows and calculation rules of the different models are highly similar. Since calculation rules in MAMBO are comparable and there has been a validation of MAM to MAMBO, the conclusions hold for MAMBO as well.

8.8 Validation of MAMBO proper

In 2009 two validation studies were conducted comparing MAMBO results to available empirical data.

The first study compared the MAMBO results from the spatial equilibrium model to aggregated data from the regulatory agency LNV-DR concerning individual manure transports. The main conclusion was that there are important discrepancies in data registration between the agricultural census and the data of manure transports making validation impossible. (Luesink *et al.,* 2010).

A second validation study compared MAMBO results for the year 2007 from the own manure application module concerning surplus manure to both the regulatory agency data and the Dutch-FADN data. The main conclusion from this study was that there is poor correlation between the regulatory agency data and both FADN data and MAMBO results, while the MAMBO results are in line with FADN empirical data although further research in needed to address some normality issues, which precluded the validation of MAMBO using the strictest validation procedures (see Soboh and Kruseman (2010) which is a draft report with missing parts showing the validation procedures).

The validity of the exogenous technical parameters (such as emission factors) should be tested elsewhere. Validation of MAMBO concerns measurable entities, especially those concerning economic behaviour. Validation of manure placement, surplus and use of off-farm manure and artificial fertilizers can be done using FADN data. This should be done on a regular basis preferably as a standardized procedure within the modeling framework.

In 2009 a second international review of ammonia models was published which included MAMBO (Reidy *et al*, 2009).

9 Concluding remarks

The release of MAMBO 1.x in 2007 was a milestone in a long development process. The complexity of the model and especially the data intensity of the model created a range of challenges with took some time to solve. At the same time, the release of MAMBO is the start of a range of new applications. Due to the new model structure and flexibility it has become much easier to provide an integrated analysis of policy problems in connection with other models. Furthermore the transparency of the model makes it much easier to use data from the model, besides the main output variables of MAMBO.

Version 2.x released in 2011 incorporates the main suggestions of the reviewers of MAMBO (Oenema, 2008; WOT N&M, 2010 - internal note; LEI audit team 2009, 2011) It is the state of the art micro-simulation model with respect to the economics of manure and minerals.

References

ApSimon, H.M., Barker, B.M., Kayin, S. (1993). Modelling studies of the atmospheric release and transport of ammonia in anticyclonic episodes. Atmospheric Environment Vol. 28, No. 4, 665 – 678.

Baltussen, W.H.M., C.J.A.M. de Bont, A. van den Ham, P.L.M. van Horne, R. Hoste en H.H. Luesink (2010). Gevolgen van het afschaffen van dierrechten. Den Haag, LEI, Rapport 2010-048.

Berge, E., Tarrason, L. (1992). An evaluation of Eularian advection methods for the modeling of lnag-range transport of air pollution. Norwegian Meteorological Institute report EMEP/MSC-W Note 2/92.

Beusen, A.H.W., C.C.G. Schotten, J. Roelsma en P. Groenendijk (2004). STONE 2.1, technische documentatie. Bilthoven, MNP-RIVM, Intern rapport (IMP rapport nr. M004/04).

Bommel, van, K.H.M. & H.B. van der Veen (2006). Farm strategy and continuation perspective, 96th EAAE-Seminar 'Causes and Impacts of Agricultural Structures', Taenikon, Switzerland, 2006.

Bouma, F., W. Dol, H.H. Luesink, D. Oudendag, T. Verwaart, H. Vrolijk (2002). Interactief Modelleren van de Mest Problematiek: Verslag van de Mestweek. Mimeograph. The Hague: LEI-Wageningen UR.

Brouwer, F.M., P. Hellegers, M.W. Hoogeveen and H.H. Luesink (2001). Nitrogen pollution control in the European Union: challenging the requirements of the Nitrate Directive with the Agenda 2000 proposals. International journal of agriculture resources, governance and ecology 1: 136-144.

Brouwer, F.M., C.J.A.M. De Bont and C. van Bruchem (2002). Landbouw, Milieu, Natuur en Economie. LEI, Den Haag, Rapport PR.02.02.

Bruggen, C. van (2007). Dierlijke mest en mineralen, 2005. Internetpublicatie: http://www.cbs.nl/NR/rdonlyres/EF9A77E2-C0DB-43F3-B412-FC0216668E49/0/2005dierlijkemestenmineralenart.pdf

Campens, V., Lauwers, L. (2002). Kunstmestgebruik en gewasproductie als activiteiten van de nutriëntenemissie. Studie uitgevoerd in opdracht van de Vlaamse Milieumaatschappij, MIRA, MIRA/2002/03, Centrum voor Landbouweconomie.

Cowell, D.A., Apsimon, H.M. (1998). Cost-effective strategies for the abatement of ammonia emissions from European Agriculture. Imperial College Centre for Environmental Technology, Imperial College, 48 Prince's Gardens, London SW7 2PE, U.K.

Dekker, P.H.M. (2000). Minimale gift met kunstmest per gewasgroep. Lelystad, PPO, persoonlijke mededeling.

Dekker, P.H.M. (2007). Minimale gift met kunstmest per gewasgroep. PPO, Lelystad, persoonlijke mededeling.

Dijk, W. van (1999). Advisbasis voor de bemesting van akkerbouw- en vollegrondsgroentegewassen. PAV onderdeel Wageningen UR, Lelystad, Publicatie 95.

Dijk, W. van (2004). Werkelijke werkingscoefficienten voor N in dierlijke mest. PPO, Lelystad, Werkgroep Onderbouwing Werkingscoefficienten.

Dijk, W. van, H.Prins, M.H.A. de Haan, A.G. Evers, A.L. Evers, A.L. Smit, J.F.F.P. Bos, J.R. van der Schoot, R, Schreuder, J.W. van der Wekken, A.M. van Dam, H. van Reuler en R. van der Maas (2007). Economische consquenties op bedrijfsniveau van het gebruiksnormenstelsel 2006-2009 voor de melkveehouderijen akker- en tuinbouw, studie i.h.k.v. Evaluatie Meststoffenwet 2007. PPO, Lelystad, Rapport 365.

Dol, W. (2004). Quick reference guide GSE for model builders. mimeograph dated august 2004. Nacquit. The Hague: LEI-Wageningen UR.

Dol, W. (2006). GTREE: version 2.25. mimeograph dated august 2006. Nacquit. The Hague: LEI-Wageningen UR.

Frederiksen, B. S. (1995). 'National Responses to the EC Nitrate Policy' Journal of. Environmental Planning and Management, 38, № 2, 253-260.

GAMS Development Corporation (2006). GAMS GDX facilities and tools. Washington D.C.: GAMS Development Corp. URL: www.gams.com/dd/docs/tools/gdxutils.pdf

Groenwold, J.G., D.A. Oudendag, H.H. Luesink (2001). Technische handleiding mest- en ammoniakmodel versie 1.0. LEI, Den Haag, Rapport 01.12.

Groenwold, J.G., D.A. Oudendag, H.H. Luesink, G. Cotteleer en H. Vrolijk (2002). Het mest- en ammoniakmodel. LEI, Den Haag, Rapport 8.02.03.

Ham, H. van der, C.H.G. Daatselaar, G.J. Doornewaard en D.W. de Hoop (2007). Bodemoverschotten op landbouwbedrijven, deelrapportage in het kader van de Evaluatie Meststoffenwet 2007 (EMW 2007). LEI, Den Haag, Rapport 3.07.05.

Helming, J.F.M. (2005). A model of Dutch agriculture based on Positive Mathematical Programming with regional and environmental applications, LEI, The Hague, Report PS.05.02.

Hennen, W.H.G.J. (1995) Detector : knowledge-based systems for dairy farm management support and policy analysis : methods and applications. Den Haag, LEI, Onderzoekverslag 125.

Hilst, van der, F., J.P. Lesschen, J.M.C. van Dam, M. Riksen, P.A. Verweij, J.P.M. Sanders, A.P.C. Faaij (2012). Spatial variation of environmental impacts of regional biomass chains. Renewable and sustainable energy reviews, 16(4): 2053-2069.

Hoogeveen, M.W., H.H. Luesink, G. Cotteleer en K.W. van der Hoek (2003). Ammoniakemissie, 2010. Referentiescenario en effecten van bestaand beleid en mogelijke aanscherpingen. LEI, Den Haag, Rapport 3.03.05.

Hoogeveen, M.W., H.H. Luesink, L.J. Mokveld en J.H. Wisman (2006). Uitgangspunten en berekeningen voor de milieubalans 2007. Intern rapport. LEI, Den Haag.

Hoogeveen, M.W., P.W. Blokland, H.H. Luesink, A. Netjes en H. Prins (2008a). Instrumentarium monitoring mestmarkt en enkele analyses. LEI, Den Haag, Intern rapport. LEI, Den Haag.

Hoogeveen, M.W., H.H. Luesink& J.N. Bosma (2008b). Synthese monitoring mestmarkt 2006. WOt-rapport 66. WOT Natuur & Milieu, Wageningen UR, Wageningen.

Hoop, D.W., de, H.H. Luesink, H. Prins, C.H.G. Daatselaar, K.H.M. van Bommel en L.J. Mokveld (2004). Effecten in 2006 en 2009 van Mestaccoord en nieuw EU-Landbouwbeleid. LEI, Den Haag, Rapport 6.04.23.

Hoop, J. de, F. Bunte, P.W. Blokland, H. van Kernebeek, H. Vrolijk, H. Luesink en T. de Koeijer, (2011). Economische analyse van de mestmarkt; Opties voor het stimuleren van innovaties. LEI, Den haag, Rapport 2011-046.

Hubeek, F.B. en D.W. de Hoop (2004). Mineralenmanagement in beleid en praktijk, Een Evaluatie van Beleidsinstrumenten in de Meststoffenwet (EMW 2004).LEI, Den Haag, Rapport 3.04.09.

Hutchings, N.J., Sommer, S.G., Andersen, J.M., Asman, W.A.H., (2001). A detailed ammonia emission inventory for Denmark. Atmospheric Environment 35, 1959-1968.

Jaarsveld, J.A. van (2004). The Operational Priority Substance model: Description and validation of OPS-Pro 4.1. RIVM report 500045001/2004. Bilthoven: RIVM.

Jongbloed, A.G. en P.A. Kemme (2005). De forfaitaire excretie van stikstof en fosfor door varkens, kippen, kalkoenen, eenden, konijnen en parelhoenders in 2002 en 2006. ASG, Lelystad, rapport 05/101077.

Kalvelagen , E. (2006). A simple system for logging messages to a window. Mimeograph. Washington D.C.: GAMS Development Corp.

Keplinger, K.O., Hauck, L.M. (2006). The Economics of Manure Utilization: Model and Application. Journal of Agricultural and Resource Economics 31 (2):414-440. Western Agricultural Economics Association.

Koeijer T.J., de, M.W. Hoogeveen en H.H. Luesink (2011). Synthese monitoring mestmarkt 2006-2010 (2011). Wageningen, WOT Natuur & Milieu, Rapport 116

Koeijer, T.J. de, G. Kruseman , P.W. Willem Blokland, M.W. Hoogeveen, H.H. Luesink (2012). MAMBO visie en strategisch plan 2012-2015. WOt-werkdocument 308. WOT Natuur & Milieu, Wageningen.

Kortstee, H.J.M., A.M. Bikker, A. van den Ham en M.M. van Krimpen (2011). Minder fosfor in varkensvoer; Macro-effecten, kansen en drempels. Rapport 2011-010. LEI Wageningen UR, Den Haag.

Kros, H., W.d. Vries, D.A. Oudendag & M.G.A.v. Leeuwen (2005). Plausibility of an integrated national model for the evaluation of mitigation options on agricultural nitrogen losses. 3rd international nitrogen conference; contributed papers: Nanjing (China), October 12-16, 2004, Science Press, Monmouth Junction NJ (USA), 848-858.

Kros, J., K.F.A. Frumau, A. Hensen & W. De Vries (2011). Integrated analysis of the effects of agricultural management on nitrogen fluxes at landscape scale. Environmental Pollution.

Kruseman, G. (2009). MAMBO 1.0 technical documentation. Internal document. LEI, Den Haag.

Kruseman, G. (2010). Quality based Generic GAMS modeling: Introductory guide for Version 3.0. Internal document. LEI, Den Haag.

Kruseman, G. and P.W. Blokland (2010). Update MAMBO 1.0 – 1.9. Internal document. LEI, Den Haag.

Kruseman, G.; Blokland, P.W.; Bouma, F.; Luesink, H.H.; Vrolijk, H.C.J. (2008). Micro-simulation as a tool to assess policy concerning non-point source pollution: the case of ammonia in Dutch agriculture *In*: Proceedings of the 107 th. EAAE Seminar "Modelling of agricultural and rural development policies", selected papers. (editors: Bartova, L., Gil, J.M., M'barek, R. and Ratinger, T.). JRC 42629. Luxembourg: Office for Official Publications of the European Communities.

LEI audit team (2009) LEI modellen audit verslag 2008. The Hague: LEI-Wageningen UR

LEI audit team (2011) LEI modellen audit verslag 2010. The Hague: LEI-Wageningen UR

Lesschen, J.P., P.J. Kuikman en I. van den Wyngaert (2009). Nulmeting emissie broeikasgassen Gelderse land- en tuinbouw. Alterra-rapport 1891. Alterra, Wageningen.

Lesschen, J.P., M. van den Berg, H.J. Westhoek, H.P. Witzke and O. Oenema (2011). Greenhouse gas emission profiles of European livestock sectors. Animal Feed Science & Technology, 166: 16-28.

LNV (2006). Wijziging Uitvoeringsregeling Meststoffenwet, Staatscourant 29 juni 2006, nr 124, pag 16.

LNV (2009). Vierde Nederlandse Actieprogramma betreffende de Nitraatrichtlijn (2010-2013). Den Haag, Ministerie van LNV.

Luesink, H.H. (2002). Acceptatie van mest per gewasgroep in 1996, 1997, 1998 en 1999. LEI, Den Haag.

Luesink, H.H. (2004). Ammoniak uit de landbouw verder teruggelopen. Agrimonitor 10 (3): 8.

Luesink, H.H. (2010). Testen van MAMBO: overzicht. Internal document. LEI, Den Haag.

Luesink, H.H. and G. Kruseman (2012). MAMBO versie met fosfaatdifferentiatie. Internal document, LEI, Den Haag.

Luesink, H.H. & H. van der Veen (1989). Twee modellen voor de economische evaluatie van de mestproblematiek. LEI, Den Haag, Onderzoekverslag 47.

Luesink, H.H. en A. Wisman (2005). Mineralenverbruik uit kunstmest: in 15 jaar met 40% gedaald. Agrimonitor 11 (3): 10.

Luesink, H.H., P.W. Blokland, J.N. Bosma, L.M. Mokveld, M.W. Hoogeveen (2008a) Monitoring mestmarkt 2006 Achtergronddocumentatie. Deelrapportage in het kader van de Evaluatie Meststoffenwet 2007. Rapport 2008-015, LEI, Den Haag.

Luesink, H.H., P.W. Blokland en L.J. Mokveld (2007). Mestmarkt 2009-2015, een verkenning. Rapport 3.08.04, LEI, Den Haag.

Luesink, H.H., P.W. Blokland, J.N. Bosma, M.W. Hoogeveen (2008b). Monitoring mestmarkt 2007; Achtergronddocumentatie. Rapport 2008 -090 LEI, Den Haag.

Luesink, H.H., P.W. Blokland, J.N. Bosma en M.W. Hoogeveen (2009). Monitoring mestmarkt 2008; Achtergronddocumentatie. Rapport 2008-041, LEI, Den Haag.

Luesink, H.H., P.W. Blokland, J.N. Bosma, (2010). Monitoring mestmarkt 2009; Achtergronddocumentatie. Rapport 2010-098, LEI, Den Haag.

Luesink, H.H., P.W. Blokland en J.N. Bosma (2011). Monitoring mestmarkt 2010; Achtergronddocumentatie. LEI rapport 2011-048, LEI-Wageningen UR, Den Haag.

Luesink, H.H., M.J.C. de Bode, P.W.G. Groot Koerkamp, H. Klinker, H.A.C. Verkerk en O. Oenema (2006). Protocol voor monitoring landelijke mestmarkt onder een stelsel van gebruiksnormen. WOt-Werkdocument 37. WOT Natuur & Milieu, Wageningen UR, Wageningen.

Luesink, H.H., C.H.G. Daatselaar, G.J. Doornewaard, H. Prins en D.W. de Hoop (2004). Sociaal-economische effecten en nationaal mestoverschot bij varianten van gebruiksnormen; studie in kader van evaluatie meststoffenwet. LEI, Den Haag, Rapport 3.04.08.

Luesink, H.H., A. Schouten, P.W. Blokland en M.W. Hoogeveen (2012). Ruimtelijke verdeling ammoniakemissies van beweiden en van aanwenden van mest uit de landbouw. WOt-werkdocument 298. WOT Natuur & Milieu, Wageningen UR, Wageningen.

Luesink, H.H., J. Teeuw, C.J.M. Vernooy en A.G. van der Zwaan (2000). Bodembalansen in de land- en tuinbouw in Zuid-Holland, stikstof-, fosfaat- en kalibalansen van de bodem voor 1997 LEI, Den Haag, Rapport 2.00.07.

McCarl A. Meeraus, P. van der Eijk, M. Bussieck, S. Dirkse, P. Steacy and Franz Nellissen. (2012). GAMS User Guide: 2012 Version 23.8. Texas A&M University with GAMS Development Corp. For latest version: http://www.gams.com/dd/docs/bigdocs/gams2002/mccarlgamsuserguide.pdf

Melse, R.W., Van Wagenberg, A.V., Mosquera, J. (2006). Size Reduction of Ammonia Scrubbers for Pig and Poultry Houses: Use of Conditional Bypass Vent at High Air Loading Rates. Biosystems Engineering (2006) 95 (1), 69–82.

Menzi, H., Rüttimann, L., Richner, W., Reidy, B. (2003). Dynamo: A new calculation model for dynamic ammonia inventories. International symposium on gaseous odour emissions from animal production facilities. Horsens, 2003.

MNP (2005). Milieucompendium 2005. MNP/CBS, Bilthoven en Voorburg.

MNP (2006a) Emissieregistratie. www.emissieregistratie.nl

MNP (2006b) Milieubalans 2006. MNP, Bilthoven.

Mol, de, R.M. (2004). Evaluatie van de lijst van aanbevelingen in Steenvoorden *et al.* Report Agrotechnology and food Innovations, Wageningen.

Mulder, M. (1994). Bedrijfstakverkenning en financiele analyse: Een simulatiemodel voor de glastuinbouw, onderzoekverslag 126, The Hague.

NAPAP (2005). National Acid Precipitation Assessment Program Report to Congress: An Integrated Assessment. National Science and Technology council, Washington D.C., 20502.

Oenema, O. (2004). Governmental policies and measures regulating nitrogen and phosphorus from animal manure in European agriculture. Journal of Animal Sciences 82: E196-E206.

Oenema, O. (2008) Review Mest- en Ammoniak Model voor beleidsondersteuning MAMBO, Commissie van Deskundigen Meststoffenwet, Wageningen.

Oenema, O., G.L. Velthof, N. Verdoes, P.W.G. Groot Koerkamp, A. Bannink, G.J. Monteny, H.G. van der Meeren K.J. van der Hoek (2000). Forfaitaire waarden voor gasvormige stikstofverliezen uit stallen en mestopslagen. Alterra, Wageningen, Rapport 107.

Oudendag, D.A., (1999). Validatie mest- en ammoniakmodel, vergelijking van de berekende ammoniakemissie bij stal en aanwenden met metingen. Report LEI, Den Haag.

Oudendag, D.A. en H.H. Luesink (1998). The manure model: manure, minerals (N, P and K), ammonia emission, heavy metals and the use of fertililiser in Dutch agriculture. Environmental Pollution 102 S1 (1998) 241-246.

Oudendag, D.A. en J.H.M. Wijnands (1989). Beperking van de ammoniakemissie uit dierlijke mest; een verkenning van mogelijkheden en kosten. LEI, Den Haag, Onderzoekverslag 56.

Reidy, B. U. Dammgen, H. Dohler, B. Eurich-Menden, F.K. van Evert, N.J. Hutchings, H.H. Luesink, H. Menzi, T.H. Misselbrook, G,-J. Monteny and J. Webb (2007). Comparison of models used for nationale Agricultural ammonia emission inventories in Europe: liquid manure systems. Atmospheric Environment (2007), doi:10.1016/j.atmosenv.2007.04.009.

Reidy, B., J. Webb, G.-J. Monteny, T.H. Misselbrook, H. Menzi, H.H. Luesink, N.J. Hutchings, B. Eurich-Menden, H. Döhler, U. Dämmgen (2009). Comparison of models used for national agricultural ammonia emission inventories in Europe: litter-based manure systems. Atmospheric Environment.

Robbins, A.D. (2004) GAWK: Effective AWK Programming. Boston: Free Software Foundation.

RIVM/CBS (2004). Milieucompendium 2004. RIVM/CBS, Bilthoven en Voorburg.

Ross, C.A., Scholefield, D., Jarvis, S.C. (2002). A model of ammonia volatilisation from a dairy farm: an examination of abatement strategies. Nutrient Cycling in Agroecosystems 64: 273–281, 2002. Kluwer Academic Publishers.

Schröder, J.J. ; Aarts, H.F.M. ; Bode, M.J.C. de ; Dijk, W. van ; Middelkoop, J.C. van ; Haan, M.H.A. de ; Schils, R.L.M. ; Velthof, G.L. ; Willems, W.J. (2004) Gebruiksnormen bij verschillende landbouwkundige en milieukundige uitgangspunten. Rapport 79. Wageningen: PRI.

Schröder, J.J., H.F.M. Aarts, J.C. van Middelkoop, M.H.A. de Haah, R.L.M. Schils, G.L. Velthof, B. Fraters en W.J. Willems (2005). Limits to the use of manure and mineral fertilizer in grass and silage maize production, with special reference to the EU Nitrates Directive. Wageningen, Plant Research International, Report 93.

Silvis, H.J., C.J.A.M. de Bont, J.F.M. Helming, M.G.A. van Leeuwen, F. Bunte en J.C.M. van Meijl (2009). De agrarische sector in Nederland naar 2020: Perspectieven en onzekerheden. Den Haag, LEI, Rapport 2009-021.

Smits, M.C.J., J.A. Van Jaarsveld, L.J. Mokveld, O. Vellinga, A.P. Stolk, K.W. Van der Hoek en W.A.J. Van der Pul (2005). Het 'VELD'-project: een gedetailleerde inventarisatie van de ammoniak-emissies en –concentraties in een agrarisch gebied. Report A&F, Wageningen.

Soboh, R. and G. Kruseman (2010). Verification and Validation of MAMBO results at Firm level: Testing differences of MAMBO simulation outcomes concerning Manure surplus and uptake of off-farm manure with real data from FADN and the Regulatory Agency. Internal report. LEI Den Haag.

Staalduinen, L.C. van, M.W. Hoogeveen, H.H. Luesink, G. Cotteleer, H. van Zeijts, P.H.M. Dekker en C.A.J.M. de Bont (2002). Actualisering landelijk mestoverschot 2003, In opdracht van de Permanente Commissie van Deskundigen Mest- en Ammoniakproblematiek. Reeks Milieuplanbureau 18, LEI, Den Haag.

Starmans, D.A.J. and K.W. van der Hoek (2007). Ammonia the case of The Netherlands. Wageningen Academic Publishers, Wageningen.

Steenvoorden, J.H.A.M., W.J. Bruins, M.M. Van Eerdt, M.W. Hoogeveen, N.J.P. Hoogervorst, J.F.M. Huijsmans, H. Leneman, H.G. Van der Meer, G.J. Monteny and F.J. De Ruiter (1999). Monitoring van nationale ammoniakemissies uit de landbouw. Op weg naar een verbeterde rekenmethodiek. Report Staring-centrum, Wageningen.

Tamminga, S., F. Aarts, A. Bannink, O. Oenema en G.J. Monteny (2004). Actualisering van geschatte N en P excreties door rundvee.

Velthof, G.L., C. van Bruggen, C.M. Groenestein, B.J. de Haan, M.W. Hoogeveen en J.F.M.Huijsmans (2009b). Methodiek voor berekening van ammoniakemissie in Nederland. WOt-rapport 70, WOT Natuur & Milieu, Wageningen UR, Wageningen.

Velthof, G.L., Oudendag, D., Witzke, H.P., Asman, W.A.H., Klimont, Z. and Oenema, O. (2009a). Integrated assessment of nitrogen emissions from agriculture in EU-27 using MITERRA-Europe. Journal of Environmental Quality, 38:402–417.

Vrolijk H.C.J., P.W. Blokland, F. Bouma, W. Dol, H. Luesink, G. Kruseman and L. Mokveld (2009a). MAMBO: Design principles, model structure and data use, interne nota, LEI, The Hague.

Vrolijk H.J.C., P.W. Blokland, J. Helming, H. Luesink, H. Prins, (2010). Economische gevolgen van een beperking van de veestapel. Rapport 2010-020, LEI, Den Haag.

Vrolijk, H.J.C., J. Helming, H. Luesink, P.W. Blokland, D, Oudendag, M. Hoogeveen, H. van Oostenbrugge en J. Smit (2009b). Nationale emissieplafonds 2010; Impact op de Nederlandse landbouw en visserij. LEI, Den Haag, Rapport 2008-069.

Walle, F.B., de, and Sevenster, J. (1998). Agriculture and the environment; Minerals, Manure and Measures. Kluwer Academic Publishers, Dordrecht, 211.

Webb, J., Misselbrook, T.H. (2004). A mass-flow model of ammonia emissions from UK livestock production. Atmospheric Environment 38 (2004) 2163-2176.

Wijnands, J. en H.H. Luesink (1984). Een economische analyse van transport en verwerking van mestoverschotten in Nederland. LEI, Den Haag, Onderzoekverslag 12.

Willems, W.J., A.H.W. Beusen, L.V. Renaud, H.H. Luesink, J.G. Conijn, H.P. Oosterom, G.J. van den Born, J.G. Kroes, P. Groenendijk en O.F. Schoumans (2005). Nutriëntenbelasting van bodem en water, verkenning van de gevolgen van het nieuwe mestbeleid. MNP, Bilthoven, Rapport 500031003/2005.

Willems, W.J., A.H.W. Beusen, L.V. Renaud, H.H. Luesink, J.G. Conijn, G.J. van den Born, J.G. Kroes, P. Groenendijk en O.F. Schoumans (2007). Prognose milieugevolgen van het nieuwe mestbeleid. Achtergrond rapport Evaluatie Meststoffenwet 2007. MNP, Bilthoven, Rapport 500124002.

Wolf, J., A. H. W. Beusen, P. Groenendijk, T. Kroon, R. Rötter and H. van Zeijts (2003). The integrated modeling system STONE for calculating nutrient emissions from agriculture in the Netherlands, Environmental modelling and software, vol. 18, pp. 597 – 617.

Wossink, G.A.A. (2000). Environmental economics of the farm firm. Wageningen: Wageningen University.

Appendix 1 Example animal categories 2006

Animal categories
Dairy cows ex. suckler cows
Female dairy cattle under one year old
Male dairy cattle under one year old
Female dairy cattle over one year old
Male dairy cattle one to two year old
Male dairy cattle over two years old
Female beef cattle grazing under one year old
Female beef cattle grazing one to two years old
Never calved female beef cattle grazing over two years old
Other beef and dairy cattle over two years
Male beef cattle non-grazing under one year old
Male beef cattle non-grazing one to two years old
Male beef cattle non-grazing over two years old
White meat calves for fattening
Red meat calves for fattening
Ewes
Lambs
Rams
Milk goats
Other goats
Horses under three years old
Horses three years and older
Ponies under three years old
Ponies three years and older
Pigs for fattening over 25 kg
Breeding sows and boars over 25 kg
Sows
Boars not mature
Boars mature
Laying hen incl. cocks under 18 weeks old incl. chickens
Laying hen incl. cocks over 18 weeks old incl. breeding hen
Breeding hen for broilers under 5 months old
Breeding hen for broilers over 5 months old
Breeding hen for laying hen under 18 weeks
Breeding hen for laying hen over 18 weeks
Broilers
Turkey
Ducks
Breeding rabbits (does)
Minks
Blue foxes
Other fur animals

Appendix 2 Model runs

Run	Baserun	Comparison run	Scenario	Test discipline
Projects STONE/manure market 2006				
NLD_P30883_2005	Yes	MAM 2005	No	Basic assumptions Expert judgement MAM 2005 results
NLD_P30883_2009_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_2015_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_2015_hv2_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_ AcceptDegreeMin/Plus_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_ AnimalNumbersMin/Plus_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_ DerogationFirmsMin_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_ FertMinContentMin/Plus_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_ MaxExportMin/Plus_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_ MinFertApplMin/Plus_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_ Optimistic_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
NLD_P30883_ Pessimistic_2005	No	NLD_P30883_2005	Yes	Basic assumptions Expert judgement Base run
Situation Manure Market 2009-2015				
NLD_P30945_2009_hv1_2006	Yes	NLD_P30883_2009_2005	Yes	Basic assumptions Expert judgement
NLD_P30945_2009_hv2_2006	No	NLD_P30945_2009_hv1_2006	Yes	Basic assumptions Expert judgement
NLD_P30945_2012_hv1_2006	No	NLD_P30945_2009_hv1_2006	Yes	Basic assumptions Expert judgement

Run	**Baserun**	**Comparison run**	**Scenario**	**Test discipline**
NLD_P30945_2012_hv2_2006	No	NLD_P30945_2012_hv1_2006	Yes	Basic assumptions Expert judgement
NLD_P30945_2015_hv1_2006	No	NLD_P30883_2015_2005	Yes	Basic assumptions Expert judgement
NLD_P30945_2015_hv2_2006	No	NLD_P30945_2015_hv1_2006	Yes	Basic assumptions Expert judgement
NLD_P30945_2009_Optimistic_2006	No	NLD_P30945_2009_hv1_2006	Yes	Basic assumptions Expert judgement
NLD_P30945_2009_Pessimistic_2006	No	NLD_P30945_2009_hv1_2006	Yes	Basic assumptions Expert judgement
Manure Market 2007				
NLD_P30909_2006	Yes	NLD_P30883_2005	No	Basic assumptions Expert judgement
MB 2006				
NLD_P30916_2006	Yes	NLD_P30909_2006	No	Basic assumptions Expert judgement

Appendix 3 Full control variable list

Control variable name	Description	Control variable type	Valid values	Valid value description	Default value
MAMBOSTONEinputloc	location of MAMBO input data	list	scenarioID	years are the scenario identifiers and data is under input/mambo	
			DataVariantList	a list of locations and type of file is provided at datavariant level	
FT_STONE_PGCL	input file type for Plot_Gemeente_CleanBodem_Landgebruik file	list	csv		
			xls		
FTO_STONE_PGCL	original input file type for Plot_Gemeente_CleanBodem_Landgebruik file	list	csv		
			xls		
FD_STONE_PGCL	format definition for input file for Plot_Gemeente_CleanBodem_Landgebruik	list	March2010	implicit definition by Leo Renaud of ALTERRA dated february 17 2010	
			October2010	implicit definition by Leo Renaud of ALTERRA dated 12 - 10 - 2010	
Tup_STONE_PGCL	tuples and subsets related to MAMBO STONE	list	BaseSTONE	basic classification concordances	BaseSTONE
FT_STONE_AF	input file type for Areaalfracties file	list	csv		
			xls		
FD_STONE_AF	format definition for input file for Plot_Gemeente_CleanBodem_Landgebruik	list	March2010	definition by Leo Renaud of ALTERRA dated February 16 2010	
DIT_RA_P_Diff	input file type for regulatory agency P differentiation	list	csv		
			xls		
MIT_RA_P_Diff	original input file type for regulatory agency P differentiation	list	csv		
			xls		
DTD_RA_P_Diff	format definition for input file for regulatory agency P differentiation file	list	sep-10	definition by Annet Bosma of LNV DR dated	sep-10
DIT_RA_cropP_Diff	input file type for regulatory agency P differentiation	list	csv		
			xls		
MIT_RA_cropP_diff	original input file type for regulatory agency P differentiation	list	csv		
			xls		
DTD_RA_cropP_Diff	format definition for input file for regulatory agency P differentiation file	list	sep-10	definition by Annet Bosma of LNV DR dated	sep-10

Control variable name	Description	Control variable type	Valid values	Valid value description	Default value
DIT_PKT2MAMBO	input file type for concordance information file concerning iPKTSoort and iCrops	list	gms		
			csv		
MIT_PKT2MAMBO	original input file type for concordance information file concerning iPKTSoort and iCrops	list	gms		
			csv		
DTD_PKT2MAMBO	format definition for input file for concordance information file concerning iPKTSoort and iCrops	list	GMS	definition in terms of GAMS code including MIF info	GMS
ModelYearPDiff	year of P differentation data	list	2010		
ChangeTANFraction		yn	yes or no		
WhatToCalc		list	normal		
			TAN		
OL_FertilizerMinContent		list	%MODELFWROOT%%ModelCode%\MAMBO\DMCT\Output		
SingleSTONEplottype	how to know what plots to use in the analysis	list	integer	STONEplot ID without prefix	default20110222
			GDXFile	GDX file with STONEplot IDs as a set memebrship list	
CalcOption	calculation method Application utilization: MAMBO (LEI),CBS (method according to CBS)	list	MAMBO		MAMBO
			CBS		
testDDC	global for testing single firm in DDC	list	yes		
			no		
ACDCOrderT	Defining the Animal category and department category order for the time fraction correction calculation	list	MAMStandard		MAMBO2008
			MAMBO1990		
AllowedExcessMargin		list	fixed	fixed excess margin	
			no	excess margin not allowed	
AnMinPAE_TF		list	Fixed	MAMBO calculation for fixed mineral production	Fixed
			Calculated	MAM calculation, no fixed mineral production	
AnimalNumberSA	Sensitivity analysis	yn	yes or no		
AnimalNumberSA_v	Sensitivity analysis	yn	yes or no		
ApplicationEmissionSA	Sensitivity analysis	yn	yes or no		
CCSetDef		list	Classic		2006
			Stone		

Control variable name	Description	Control variable type	Valid values	Valid value description	Default value
percentagehere		list	0.05		
			0.06		
testLMS_by_ST		yn	yes or no		
CropAreaSA	Sensitivity analysis	yn	yes or no		
CropAreaSA_v	Sensitivity analysis	yn	yes or no		
Country		list	NLD	Netherlands	NLD
			DEU	Germany	
DepartmentDistriSA	Sensitivity analysis	yn	yes or no		
DepartmentDistriSA_v	Sensitivity analysis	yn	yes or no		
Excretion		list	ureumfixed	ureum data exougenous	ureumfixed
			Ureumcalc	ureum calculated internally	
FertilizerMinContentSA	Sensitivity analysis	yn	yes or no		
Fertilizersetdef		list	MAM		MAMBO
			MAMBO		
FertMinCont		list	Forfaitair		
			Scientific		
FixFertMinContentSA	Sensitivity analysis	yn	yes or no		
LegalFertStandardSA	Sensitivity analysis	yn	yes or no		
LegalFertStandardSA_v	Sensitivity analysis	yn	yes or no		
LegalManureStandard		list	Normal	without SoilType	
			BySoilType	with SoilType	
LegalManureStandardSA	Sensitivity analysis	yn	yes or no		
LegalManureStandardSA_v	Sensitivity analysis	yn	yes or no		
ManureExportSA	Sensitivity analysis	yn	yes or no		
ManureProcessSA	Sensitivity analysis	yn	yes or no		
Mineralcontent		list	fixed	content fixed by regulations	fixed
			Agricultural	best scientific guess	
MinimalFertilizerApplSA	Sensitivity analysis	yn	yes or no		
MinFertApplSoilType		list	yes	yes	yes
			no	no	
New_TFC		yn	yes or no		
NoTFC		yn	yes or no		
ExcessMargin		yn	yes or no		
PastureEmissionSA	Sensitivity analysis	yn	yes or no		
PastProbThreshold		list	99.9		
StableEmissionSA	Sensitivity analysis	yn	yes or no		
Standards2Use		list	LMS_LFS_MFA	legal manure standard corrected for fertilizer manure standard and fertilizer apllication standard	LMS_LFS_MFA
			LMS	Only legal manure standard	
StorageEmissionSA	Sensitivity analysis	yn	yes or no		

Control variable name	**Description**	**Control variable type**	**Valid values**	**Valid value description**	**Default value**
StepwiseTM		yn	yes or no		
StorageSurplus		yn	yes or no		
TANorBasic		list	TAN	TAN calculation rules	
			Basic	Basic calulation rules	
TolTFC	Tolerance level for deciding when time fraction correction is ok	list	0.001	Tollerance Time Fraction	
			0.002	Or any kind of number	
UDderogation	Where to find derogation data	list	External	external derogation data	external
			no	no derogation	
UDSettings	Original control MAMBO 1.0 variable	list	M0701	MAMBO	
			Classic	MAM	
UDvariant	Original control MAMBO 1.0 variable allowing for lenience in mineral standards	list	all5		
			no		
UreaContentSA	Sensitivity analysis	yn	yes or no		
ureascientific	Calculate N content of manure based on urea content of milk instead of using tables	yn	yes or no		
UseDDF		yn	yes or no		
UseDDF_v		yn	yes or no		
WhenToUseCropOrder		list	JustNoSurplus		
			Always		
TimeOfMinAndImmobil		list	start		
			end		
SpecificPastureEmission		yn	yes or no		
FirmApplModel	what kind of model for the firm level manure placement is used	list	RBFM	MAM style rule based firm model with extended fertilizer categories	test
			LPfirm	LP model introduced with P differentiation	
Manurelegislation		yn	yes or no		
checkinfeas		yn	yes or no		
firmtest		yn	yes or no		
muntest		yn	yes or no		
weightObj001a	Weight of manure disposal cost minimization in firm level LP	list	0.9		
weightObj001c	Weight of other objectives	list	0.1		
			0.05		
AllowManTrnspToOtherRegions	Control in spatial equilibrium model	yn	yes or no		
AllowManTrnspToExport	Control in spatial equilibrium model	yn	yes or no		
AllowManProcessed	Control in spatial	yn	yes or no		

Control variable name	Description	Control variable type	Valid values	Valid value description	Default value
	equilibrium model				
AllowManDumped	Control in spatial equilibrium model	yn	yes or no		
AcceptDegreeCalc	Control in spatial equilibrium model	list	MAM		
			Storage		
Allow_TwoPhaseRun	Control in spatial equilibrium model	yn	yes or no		
BonusOwnRegion	Control in spatial equilibrium model	list	0		
			1		
CalibratedTransport	Control in spatial equilibrium model	list	no		
			Dienstregelingen		
CropManureRequirement		list	4		
			5		
DoTransformMinerals		yn	yes or no		
expandFix		list	0		
			1		
expandFixstep		list	0.005		
			0.006		
FixedCostExport		list	0.5		
			0.6		
fixprocessat0		yn	yes or no		
FMCaEM_FC		list	Hans		
			Oldweight		
isteps_step		list	0.1		
			0.2		
OptionSolver		list	Cplex		
			Minos		
OptionSolverNLP		list	Minos		
			Conopt		
PenaltyADmin		list	0		
			1		
PenaltyADPos		list	6		
			7		
penaltyFactor		list	1000		
			2000		
postRBFM		list	Agric		
			fixed		
regionalized		yn	yes or no		
SkipPosRevenues		yn	yes or no		
Solve		yn	yes or no		
storagecosts		list	value		

Control variable name	Description	Control variable type	Valid values	Valid value description	Default value
			external		
StorageCostsValue		list	0		
			100		
Test_FMinContentAfterEm_FC		yn	yes or no		
UseAcceptationDegree		yn	yes or no		
useSmartBounds		yn	yes or no		
UseStartValues		yn	yes or no		
CategoryClass		list	FCL_CCL		
			Categories		
avgpercgrazing_region1		list	1		
			0.5		
avgpercgrazing_region2		list	1		
			0.5		
ChangeSoils		yn	yes or no		
original		list	4		
CSsuffix		list	7		
UseMineralUseArtFert		yn	yes or no		
testAEFirm		yn	yes or no		
Harrytest		yn	yes or no		
stepwiseTM		yn	yes or no		
TestFraction		yn	yes or no		
FixMinEffectCoefficient		yn	yes or no		
test_FixMinEffectCoeff1		yn	yes or no		
UseDRmanure		yn	yes or no		
oneshot		yn	yes or no		
NminFraction		list	F1		
totalAFtuse_dim		list	Kg		
			MT		
AFC_agglevel		list	ProvinceAggCCL		
			Crops		
GH_fertUse		list	Second_Province2Nat		
StepwiseAFC		yn	yes or no		
AFCCorUpperbound		string	<alpha numerical string>		
AFCtype		list	MAMBO	standard porocedure from MAMBO 1.x	MAMBO
			Upperbound	upperbbound of artilicial fertilizer use above potential	
FADNspecificMineralsEL		string	<alpha numerical string>		
Aggregationlevel		list	MAMBO		
			MAM		

Control variable name	Description	Control variable type	Valid values	Valid value description	Default value
AnimalDate		string	<alpha numerical string>		
CropDate		string	<alpha numerical string>		
Datayear		string	<alpha numerical string>		
DataVersionDR		string	<alpha numerical string>		
Calibration		yn	yes or no		
ModelYear		string	<alpha numerical string>		
newgrids		yn	yes or no		
NoAFC		yn	yes or no		
RawDataSourceDR		string	<alpha numerical string>		
DataVersionDR		string	<alpha numerical string>		
VersionData		string	<alpha numerical string>		
DoGridreport	run grid reporting	yn	yes or no		no
Minorgratio	ratio of mineral to different types of organic Nitrogen	list	MAMBO		
			NR_60_20_20		
P_orgmin_Fraction_FC		list	AB90		
			AB80		
p_orgmin_version		list	18-jan-11		
			GDX		
FillArtFert2Max	fill out artificial fertilizer to max of norms or fertilizer recommendation	list	calib	use calibrated fertilizer data	calib
			max	only use artificial fertilizer filled out to maximum	
Pdifferentiation		yn	yes or no		
Pdifferentiationold		yn	yes or no		
correctionfactorPdiffArea		list	100	data in are	
			1	data in hectare	
cl_iPolicyRegionST	identifier for policy regions based on dominant soil type	list	domST9	policy regions based on 9 dominant soil types first developed for STONE and EMW2012	domST9

Verschenen documenten in de reeks Werkdocumenten van de Wettelijke Onderzoekstaken Natuur & Milieu vanaf 2009

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2009

126 *Kamphorst, D.A.* Keuzes in het internationale biodiversiteitsbeleid; Verkenning van de beleidstheorie achter de internationale aspecten van het Beleidsprogramma Biodiversiteit (2008-2011)
127 *Dirkx, G.H.P. & F.J.P. van den Bosch.* Quick scan gebruik Catalogus groenblauwe diensten
128 *Loeb, R. & P.F.M. Verdonschot.* Complexiteit van nutriëntenlimitaties in oppervlaktewateren
129 *Kruit, J. & P.M. Veer.* Herfotografie van landschappen; Landschapsfoto's van de 'Collectie de Boer' als uitgangspunt voor het in beeld brengen van ontwikkelingen in het landschap in de periode 1976-2008
130 *Oenema, O., A. Smit & J.W.H. van der Kolk.* Indicatoren Landelijk Gebied; werkwijze en eerste resultaten
131 *Agricola, H.J.A.J. van Strien, J.A. Boone, M.A. Dolman, C.M. Goossen, S. de Vries, N.Y. van der Wulp, L.M.G. Groenemeijer, W.F. Lukey & R.J. van Til.* Achtergronddocument Nulmeting Effectindicatoren Monitor Agenda Vitaal Platteland
132 *Jaarrapportage 2008.* WOT-04-001 – Koepel
133 *Jaarrapportage 2008.* WOT-04-002 – Onderbouwend Onderzoek
134 *Jaarrapportage 2008.* WOT-04-003 – Advisering Natuur & Milieu
135 *Jaarrapportage 2008.* WOT-04-005 – M-AVP
136 *Jaarrapportage 2008.* WOT-04-006 – Natuurplanbureaufunctie
137 *Jaarrapportage 2008.* WOT-04-007 – Milieuplanbureaufunctie
138 *Jong de, J.J., J. van Os & R.A. Smidt.* Inventarisatie en beheerskosten van landschapselementen
139 *Dirkx, G.H.P., R.W. Verburg & P. van der Wielen.* Tegenkrachten Natuur. Korte verkenning van de weerstand tegen aankopen van landbouwgrond voor natuur
140 *Annual reports for 2008; Programme WOT-04*
141 *Vullings, L.A.E., C. Blok, G. Vonk, M. van Heusden, A. Huisman, J.M. van Linge, S. Keijzer, J. Oldengarm & J.D. Bulens.* Omgaan met digitale nationale beleidskaarten
142 *Vreke, J.,A.L. Gerritsen, R.P. Kranendonk, M. Pleijte, P.H. Kersten & F.J.P. van den Bosch.* Maatlat Government – Governance
143 *Gerritsen, A.L., R.P. Kranendonk, J. Vreke, F.J.P. van den Bosch & M. Pleijte.* Verdrogingsbestrijding in het tijdperk van het Investeringsbudget Landelijk Gebied. Een verslag van casusonderzoek in de provincies Drenthe, Noord-Brabant en Noord-Holland
144 *Luesink, H.H., P.W. Blokland, M.W. Hoogeveen & J.H. Wisman.* Ammoniakemissie uit de landbouw in 2006 en 2007
145 *Bakker de, H.C.M. & C.S.A. van Koppen.* Draagvlakonderzoek in de steigers. Een voorstudie naar indicatoren om maatschappelijk draagvlak voor natuur en landschap te meten
146 *Goossen, C.M.,* Monitoring recreatiegedrag van Nederlanders in landelijke gebieden. Jaar 2006/2007
147 *Hoefs, R.M.A., J. van Os & T.J.A. Gies.* Kavelruil en Landschap. Een korte verkenning naar ruimtelijke effecten van kavelruil
148 *Klok, T.L., R. Hille Ris Lambers, P. de Vries, J.E. Tamis & J.W.M. Wijsman.* Quick scan model instruments for marine biodiversity policy
149 *Spruijt, J., P. Spoorenberg & R. Schreuder.* Milieueffectiviteit en kosten van maatregelen gewasbescherming
150 *Ehlert, P.A.I. (rapporteur).* Advies Bemonstering bodem voor differentiatie van fosfaatgebruiksnormen
151 *Wulp van der, N.Y.* Storende elementen in het landschap: welke, waar en voor wie? Bijlage bij WOt-paper 1 – Krassen op het landschap
152 *Oltmer, K., K.H.M. van Bommel, J. Clement, J.J. de Jong, D.P. Rudrum & E.P.A.G. Schouwenberg.* Kosten voor habitattypen in Natura 2000-gebieden. Toepassing van de methode Kosteneffectiviteit natuurbeleid
153 *Adrichem van, M.H.C., F.G. Wortelboer & G.W.W. Wamelink (2010).* MOVE. Model for terrestrial Vegetation. Version 4.0
154 *Wamelink, G.W.W., R.M. Winkler & F.G. Wortelboer.* User documentation MOVE4 v 1.0
155 *Gies de, T.J.A., L.J.J. Jeurissen, I. Staritsky & A. Bleeker.* Leefomgevingsindicatoren Landelijk gebied. Inventarisatie naar stand van zaken over geurhinder, lichthinder en fijn stof
156 *Tamminga, S., A.W. Jongbloed, P. Bikker, L. Sebek, C. van Bruggen & O. Oenema.* Actualisatie excretiecijfers landbouwhuisdieren voor forfaits regeling Meststoffenwet
157 *Van der Salm, C., L. .M. Boumans, G.B.M. Heuvelink & T.C. van Leeuwen.* Protocol voor validatie van het nutriëntenemissiemodel STONE op meetgegevens uit het Landelijk Meetnet effecten Mestbeleid
158 *Bouwma, I.M.* Quickscan Natura 2000 en Programma Beheer. Een vergelijking van Programma Beheer met de soorten en habitats van Natura 2000
159 *Gerritsen, A.L., D.A. Kamphorst, T.A. Selnes, M. van Veen, F.J.P.van den Bosch, L. van den Broek, M.E.A. Broekmeyer, J.L.M. Donders, R.J. Fontein, S. van Tol, G.W.W. Wamelink & P. van der Wielen.* Dilemma's en barrières in de praktijk van het natuur- en landschapsbeleid; Achtergronddocument bij Natuurbalans 2009
160 *Fontein R.J, T.A. de Boer, B. Breman, C.M. Goossen, R.J.H.G. Henkens, J. Luttik & S. de Vries.* Relatie recreatie en natuur; Achtergronddocument bij Natuurbalans 2009
161 *Deneer, J.W. & R. Kruijne. (2010).* Atmosferische depositie van gewasbeschermingsmiddelen. Een verkenning van de literatuur verschenen na 2003
162 *Verburg, R.W., M.E. Sanders, G.H.P. Dirkx, B. de Knegt & J.W. Kuhlman.* Natuur, landschap en landelijk gebied. Achtergronddocument bij Natuurbalans 2009
163 *Doorn van, A.M. & M.P.C.P. Paulissen.* Natuurgericht milieubeleid voor Natura 2000-gebieden in Europees perspectief: een verkenning
164 *Smidt, R.A., J. van Os & I. Staritsky.* Samenstellen van landelijke kaarten met landschapselementen, grondeigendom en beheer. Technisch achtergronddocument bij de opgeleverde bestanden
165 *Pouwels, R., R.P.B. Foppen, M.F. Wallis de Vries, R. Jochem, M.J.S.M. Reijnen & A. van Kleunen,* Verkenning LARCH: omgaan met kwaliteit binnen ecologische netwerken
166 *Born van den, G.J., H.H. Luesink, H.A.C. Verkerk, H.J. Mulder, J.N. Bosma, M.J.C. de Bode & O. Oenema,* Protocol voor monitoring landelijke mestmarkt onder een stelsel van gebruiksnormen, versie 2009
167 *Dijk, T.A. van, J.J.M. Driessen, P.A.I. Ehlert, P.H. Hotsma, M.H.M.M. Montforts, S.F. Plessius & O. Oenema.* Protocol beoordeling stoffen Meststoffenwet- Versie 2.1
168 *Smits, M.J., M.J. Bogaardt, D. Eaton, A. Karbauskas & P. Roza.* De vermaatschappelijking van het Gemeenschappelijk Landbouwbeleid. Een inventarisatie van visies in Brussel en diverse EU-lidstaten
169 *Vreke, J. & I.E. Salverda.* Kwaliteit leefomgeving en stedelijk groen
170 *Hengsdijk, H. & J.W.A. Langeveld.* Yield trends and yield gap analysis of major crops in the World
171 *Horst, M.M.S. ter & J.G. Groenwold.* Tool to determine the coefficient of variation of DegT50 values of plant protection products in water-sediment systems for different values of the sorption coefficient

172 *Boons-Prins, E., P. Leffelaar, L. Bouman & E. Stehfest (2010)* Grassland simulation with the LPJmL model

173 *Smit, A., O. Oenema & J.W.H. van der Kolk.* Indicatoren Kwaliteit Landelijk Gebied

2010

174 *Boer de, S., M.J. Bogaardt, P.H. Kersten, F.H. Kistenkas, M.G.G. Neven & M. van der Zouwen.* Zoektocht naar nationale beleidsruimte in de EU-richtlijnen voor het milieu- en natuurbeleid. Een vergelijking van de implementatie van de Vogel- en Habitatrichtlijn, de Kaderrichtlijn Water en de Nitraatrichtlijn in Nederland, Engeland en Noordrijn-Westfalen

175 *Jaarrapportage 2009.* WOT-04-001 – Koepel

176 *Jaarrapportage 2009.* WOT-04-002 – Onderbouwend Onderzoek

177 *Jaarrapportage 2009.* WOT-04-003 – Advisering Natuur & Milieu

178 *Jaarrapportage 2009.* WOT-04-005 – M-AVP

179 *Jaarrapportage 2009.* WOT-04-006 – Natuurplanbureaufunctie

180 *Jaarrapportage 2009.* WOT-04-007 – Milieuplanbureaufunctie

181 *Annual reports for 2009;* Programme WOT-04

182 *Oenema, O., P. Bikker, J. van Harn, E.A.A. Smolders, L.B. Sebek, M. van den Berg, E. Stehfest & H. Westhoek.* Quickscan opbrengsten en efficiëntie in de gangbare en biologische akkerbouw, melkveehouderij, varkenshouderij en pluimveehouderij. Deelstudie van project 'Duurzame Eiwitvoorziening'

183 *Smits, M.J.W., N.B.P. Polman & J. Westerink.* Uitbreidingsmogelijkheden voor groene en blauwe diensten in Nederland; Ervaringen uit het buitenland

184 *Dirkx, G.H.P. (red.).* Quick responsefunctie 2009. Verslag van de werkzaamheden

185 *Kuhlman, J.W., J. Luijt, J. van Dijk, A.D. Schouten & M.J. Voskuilen.* Grondprijskaarten 1998-2008

186 *Slangen, L.H.G., R.A. Jongeneel, N.B.P. Polman, E. Lianouridis, H. Leneman & M.P.W. Sonneveld.* Rol en betekenis van commissies voor gebiedsgericht beleid

187 *Temme, A.J.A.M. & P.H. Verburg.* Modelling of intensive and extensive farming in CLUE

188 *Vreke, J.* Financieringsconstructies voor landschap

189 *Slangen, L.H.G.* Economische concepten voor beleidsanalyse van milieu, natuur en landschap

190 *Knotters, M., G.B.M. Heuvelink, T. Hoogland & D.J.J. Walvoort.* A disposition of interpolation techniques

191 *Hoogeveen, M.W., P.W. Blokland, H. van Kernebeek, H.H. Luesink & J.H. Wisman.* Ammoniakemissie uit de landbouw in 1990 en 2005-2008

192 *Beekman, V., A. Pronk & A. de Smet.* De consumptie van dierlijke producten. Ontwikkeling, determinanten, actoren en interventies.

193 *Polman, N.B.P., L.H.G. Slangen, A.T. de Blaeij, J. Vader & J. van Dijk.* Baten van de EHS; De locatie van recreatiebedrijven

194 *Veeneklaas, F.R. & J. Vader.* Demografie in de Natuurverkenning 2011; Bijlage bij WOt-paper 3

195 *Wascher, D.M., M. van Eupen, C.A. Mücher & I.R. Geijzendorffer,* Biodiversity of European Agricultural landscapes. Enhancing a High Nature Value Farmland Indicator

196 *Apeldoorn van, R.C., I.M. Bouwma, A.M. van Doorn, H.S.D. Naeff, R.M.A. Hoefs, B.S. Elbersen & B.J.R. van Rooij.* Natuurgebieden in Europa: bescherming en financiering

197 *Brus, D.J.,, R. Vasat, G. B. M. Heuvelink, M. Knotters, F. de Vries & D. J. J. Walvoort.* Towards a Soil Information System with quantified accuracy; A prototype for mapping continuous soil properties

198 *Groot, A.M.E.& A.L. Gerritsen, m.m.v. M.H. Borgstein, E.J. Bos & P. van der Wielen.* Verantwoording van de methodiek Achtergronddocument bij 'Kwalitatieve monitor Systeeminnovaties verduurzaming landbouw'

199 *Bos, E.J. & M.H. Borgstein.* Monitoring Gesloten voer-mest kringlopen. Achtergronddocument bij 'Kwalitatieve monitor Systeeminnovaties verduurzaming landbouw'

200 *Kennismarkt 27 april 2010;* Van onderbouwend onderzoek Wageningen UR naar producten Planbureau voor de Leefomgeving

201 *Wielen van der, P.* Monitoring Integrale duurzame stallen. Achtergronddocument bij 'Kwalitatieve monitor Systeeminnovaties verduurzaming landbouw'

202 *Groot, A.M.E.& A.L. Gerritsen.* Monitoring Functionele agrobiodiversiteit. Achtergrond-document bij 'Kwalitatieve monitor Systeeminnovaties verduurzaming landbouw'

203 *Jongeneel, R.A. & L. Ge.* Farmers' behavior and the provision of public goods: Towards an analytical framework

204 *Vries, S. de, M.H.G. Custers & J. Boers.* Storende elementen in beeld; de impact van menselijke artefacten op de landschapsbeleving nader onderzocht

205 *Vader, J. J.L.M. Donders & H.W.B. Bredenoord.* Zicht op natuur- en landschapsorganisaties; Achtergronddocument bij Natuurverkenning 2011

206 *Jongeneel, R.A., L.H.G. Slangen & N.B.P. Polman.* Groene en blauwe diensten; Een raamwerk voor de analyse van doelen, maatregelen en instrumenten

207 *Letourneau, A.P, P.H. Verburg & E. Stehfest.* Global change of land use systems; IMAGE: a new land allocation module

208 *Heer, M. de.* Het Park van de Toekomst. Achtergronddocument bij Natuurverkenning 2011

209 *Knotters, M., J. Lahr, A.M. van Oosten-Siedlecka & P.F.M. Verdonschot.* Aggregation of ecological indicators for mapping aquatic nature quality. Overview of existing methods and case studies

210 *Verdonschot, P.F.M. & A.M. van Oosten-Siedlecka.* Graadmeters Aquatische natuur. Analyse gegevenskwaliteit Limnodata

211 *Linderhof, V.G.M. & H. Leneman.* Quickscan kosteneffectiviteitsanalyse aquatische natuur

212 *Leneman, H., V.G.M. Linderhof & R. Michels.* Mogelijkheden voor het inbrengen van informatie uit de 'KRW database' in de 'KE database'

213 *Schrijver, R.A.M., A. Corporaal, W.A. Ozinga & D. Rudrum.* Kosteneffectieve natuur in landbouwgebieden; Methode om effecten van maatregelen voor de verhoging van biodiversiteit in landbouwgebieden te bepalen, een test in twee gebieden in Noordoost-Twente en West-Zeeuws-Vlaanderen

214 *Hoogland, T., R.H. Kemmers, D.G. Cirkel & J. Hunink.* Standplaatsfactoren afgeleid van hydrologische model uitkomsten; Methode-ontwikkeling en toetsing in het Drentse Aa-gebied

215 *Agricola, H.J., R.M.A. Hoefs, A.M. van Doorn, R.A. Smidt & J. van Os.* Landschappelijke effecten van ontwikkelingen in de landbouw

216 *Kramer, H., J. Oldengarm & L.F.S. Roupioz.* Nederland is groener dan kaarten laten zien; Mogelijkheden om 'groen' beter te inventariseren en monitoren met de automatische classificatie van digitale luchtfoto's

217 *Raffe, J.K. van, J.J. de Jong & G.W.W. Wamelink* ***(2011).*** Kostenmodule Natuurplanner; functioneel ontwerp en software-validatie

218 *Hazeu, G.W., Kramer, H., J. Clement & W.P. Daamen (2011).* Basiskaart Natuur 1990rev

219 *Boer, T.A. de.* Waardering en recreatief gebruik van Nationale Landschappen door haar bewoners

220 *Leneman, H., A.D. Schouten & R.W. Verburg.* Varianten van natuurbeleid: voorbereidende kostenberekeningen; Achtergronddocument bij Natuurverkenning 2011

221 *Knegt, B. de, J. Clement, P.W. Goedhart, H. Sierdsema, Chr. van Swaay & P. Wiersma.* Natuurkwaliteit van het agrarisch gebied

2011

222 *Kamphorst, D.A. & M.M.P. van Oorschot.* Kansen en barrières voor verduurzaming van houtketens

223 *Salm, C. van der & O.F. Schoumans.* Langetermijneffecten van verminderde fosfaatgiften

224 *Bikker, P., M.M. van Krimpen & G.J. Remmelink.* Stikstof-verteerbaarheid in voeders voor landbouwhuisdieren; Berekeningen voor de TAN-excretie

225 *M.E. Sanders & A.L. Gerritsen (red.).* Het biodiversiteitsbeleid in Nederland werkt. Achtergronddocument bij Balans van de Leefomgeving 2010

226 *Bogaart, P.W., G.A.K. van Voorn & L.M.W. Akkermans.* Evenwichtsanalyse modelcomplexiteit; een verkennende studie

227 *Kleunen A. van, K. Koffijberg, P. de Boer, J. Nienhuis, C.J. Camphuysen, H. Schekkerman, K.H. Oosterbeek, M.L. de Jong, B. Ens & C.J. Smit* ***(2010).*** Broedsucces van kustbroedvogels in de Waddenzee in 2007 en 2008

228 *Salm, C. van der, L.J.M. Boumans, D.J. Brus, B. Kempen & T.C van Leeuwen.* Validatie van het nutriëntenemissiemodel STONE met meetgegevens uit het Landelijk Meetnet effecten Mestbeleid (LMM) en de Landelijke Steekproef Kaarteenheden (LSK).

229 *Dijkema, K.S., W.E. van Duin, E.M. Dijkman, A. Nicolai, H. Jongerius, H. Keegstra, L. van Egmond, H.J. Venema & J.J. Jongsma*. Vijftig jaar monitoring en beheer van de Friese en Groninger kwelderwerken: 1960-2009

230 *Jaarrapportage 2010.* WOT-04-001 – Koepel

231 *Jaarrapportage 2010.* WOT-04-002 – Onderbouwend Onderzoek

232 *Jaarrapportage 2010.* WOT-04-003 – Advisering Natuur & Milieu

233 *Jaarrapportage 2010.* WOT-04-005 – M-AVP

234 *Jaarrapportage 2010.* WOT-04-006 – Natuurplanbureaufunctie

235 *Jaarrapportage 2010.* WOT-04-007 – Milieuplanbureaufunctie

236 *Arnouts, R.C.M. & F.H. Kistenkas.* Nederland op slot door Natura 2000: de discussie ontrafeld; Bijlage bij WOt-paper 7 – De deur klemt

237 *Harms, B. & M.M.M. Overbeek.* Bedrijven aan de slag met natuur en landschap; relaties tussen bedrijven en natuurorganisaties. Achtergronddocument bij Natuurverkenning 2011

238 *Agricola, H.J. & L.A.E. Vullings.* De stand van het platteland 2010. Monitor Agenda Vitaal Platteland; Rapportage Midterm meting Effectindicatoren

239 *Klijn, J.A.* Wisselend getij. Omgang met en beleid voor natuur en landschap in verleden en heden; een essayistische beschouwing. Achtergronddocument bij Natuurverkenning 2011

240 *Corporaal, A., T. Denters, H.F. van Dobben, S.M. Hennekens, A. Klimkowska, W.A. Ozinga, J.H.J. Schaminée & R.A.M. Schrijver.* Stenoeciteit van de Nederlandse flora. Een nieuwe parameter op grond van ecologische amplitudo's van de Nederlandse plantensoorten en toepassings-mogelijkheden

241 *Wamelink, G.W.W., R. Jochem, J. van der Greft-van Rossum, C. Grashof-Bokdam, R.M.A. Wegman, G.J. Franke & A.H. Prins.* Het plantendispersiemodel DIMO. Verbetering van de modellering in de Natuurplanner

242 *Klimkowska, A., M.H.C. van Adrichem, J.A.M. Jansen & G.W.W. Wamelink.* Bruikbaarheid van WNK-monitoringgegevens voor EC-rapportage voor Natura 2000-gebieden. Eerste fase

243 *Goossen, C.M., R.J. Fontein, J.L.M. Donders & R.C.M. Arnouts.* Mass Movement naar recreatieve gebieden; Overzicht van methoden om bezoekersaantallen te meten

244 *Spruijt, J., P.M. Spoorenberg, J.A.J.M. Rovers, J.J. Slabbekoorn, S.A.M. de Kool, M.E.T. Vlaswinkel, B. Heijne, J.A. Hiemstra, F. Nouwens & B.J. van der Sluis.* Milieueffecten van maatregelen gewasbescherming

245 *Walker, A.N. & G.B. Woltjer.* Forestry in the Magnet model.

246 *Hoefnagel, E.W.J., F.C. Buisman, J.A.E. van Oostenbrugge & B.I. de Vos.* Een duurzame toekomst voor de Nederlandse visserij. Toekomstscenario's 2040

247 *Buurma, J.S. & S.R.M. Janssens.* Het koor van adviseurs verdient een dirigent. Over kennisverspreiding rond phytophthora in aardappelen

248 *Verburg, R.W., A.L. Gerritsen & W. Nieuwenhuizen.* Natuur meekoppelen in ruimtelijke ontwikkeling: een analyse van sturingsstrategieën voor de Natuurverkenning. Achtergronddocument bij Natuurverkenning 2011

249 *Kooten, T. van & C. Klok.* The Mackinson-Daskalov North Sea EcoSpace model as a simulation tool for spatial planning scenarios

250 *Bruggen van, C., C.M. Groenestein, B.J. de Haan, M.W. Hoogeveen, J.F.M. Huijsmans, S.M. van der Sluis & G.L. Velthof.* Ammoniakemissie uit dierlijke mest en kunstmest 1990-2008. Berekeningen met het Nationaal Emissiemodel voor Ammoniak (NEMA)

251 *Bruggen van, C., C.M. Groenestein, B.J. de Haan, M.W. Hoogeveen, J.F.M. Huijsmans, S.M. van der Sluis & G.L. Velthof.* Ammoniakemmissie uit dierlijke mest en kunstmest in 2009. Berekeningen met het Nationaal Emissiemodel voor Ammoniak (NEMA)

252 *Randen van, Y., H.L.E. de Groot & L.A.E. Vullings.* Monitor Agenda Vitaal Platteland vastgelegd. Ontwerp en implementatie van een generieke beleidsmonitor

253 *Agricola, H.J., R. Reijnen, J.A. Boone, M.A. Dolman, C.M. Goossen, S. de Vries, J. Roos-Klein Lankhorst, L.M.G. Groenemeijer & S.L. Deijl.* Achtergronddocument Midterm meting Effectindicatoren Monitor Agenda Vitaal Platteland

254 *Buiteveld, J. S.J. Hiemstra & B. ten Brink.* Modelling global agrobiodiversity. A fuzzy cognitive mapping approach

255 *Hal van R., O.G. Bos & R.G. Jak.* Noordzee: systeemdynamiek, klimaatverandering, natuurtypen en benthos. Achtergronddocument bij Natuurverkenning 2011

256 *Teal, L.R..* The North Sea fish community: past, present and future. Background document for the 2011 National Nature Outlook

257 *Leopold, M.F., R.S.A. van Bemmelen & S.C.V. Geelhoed.* Zeevogels op de Noordzee. Achtergronddocument bij Natuurverkenning 2011

258 *Geelhoed, S.C.V. & T. van Polanen Petel.* Zeezoogdieren op de Noordzee. Achtergronddocument bij Natuurverkenning 2011

259 *Kuijs, E.K.M. & J. Steenbergen.* Zoet-zoutovergangen in Nederland; stand van zaken en kansen voor de toekomst. Achtergronddocument bij Natuurverkenning 2011

260 *Baptist, M.J.* Zachte kustverdediging in Nederland; scenario's voor 2040. Achtergronddocument bij Natuurverkenning 2011

261 *Wiersinga, W.A., R. van Hal, R.G. Jak & F.J. Quirijns.* Duurzame kottervisserij op de Noordzee. Achtergronddocument bij Natuurverkenning 2011

262 *Wal J.T. van der & W.A. Wiersinga.* Ruimtegebruik op de Noordzee en de trends tot 2040. Achtergronddocument bij Natuurverkenning 2011

263 *Wiersinga, W.A. J.T. van der Wal, R.G. Jak & M.J. Baptist*. Vier kijkrichtingen voor de mariene natuur in 2040. Achtergronddocument bij Natuurverkenning 2011

264 *Bolman, B.C. & D.G. Goldsborough.* Marine Governance. Achtergronddocument bij Natuurverkenning 2011

265 *Bannink, A.* Methane emissions from enteric fermentation in dairy cows, 1990-2008; Background document on the calculation method and uncertainty analysis for the Dutch National Inventory Report on Greenhouse Gas Emissions

266 *Wyngaert, I.J.J. van den, P.J. Kuikman, J.P. Lesschen, C.C. Verwer & H.H.J. Vreuls.* LULUCF values under the Kyoto Protocol; Background document in preparation of the National Inventory Report 2011 (reporting year 2009)

267 *Helming, J.F.M. & I.J. Terluin.* Scenarios for a cap beyond 2013; implications for EU27 agriculture and the cap budget.

268 *Woltjer, G.B.* Meat consumption, production and land use. Model implementation and scenarios.

269 *Knegt, B. de, M. van Eupen, A. van Hinsberg, R. Pouwels, M.S.J.M. Reijnen, S. de Vries, W.G.M. van der Bilt & S. van Tol.* Ecologische en recreatieve beoordeling van toekomstscenario's van natuur op het land. Achtergronddocument bij Natuurverkenning 2011.

270 *Bos, J.F.F.P., M.J.W. Smits, R.A.M Schrijver & R.W. van der Meer*. Gebiedsstudies naar effecten van vergroening van het Gemeenschappelijk Landbouwbeleid op bedrijfseconomie en inpassing van agrarisch natuurbeheer.

271 *Donders, J., J. Luttik, M. Goossen, F. Veeneklaas, J. Vreke & T. Weijschede.* Waar gaat dat heen? Recreatiemotieven, landschapskwaliteit en de oudere wandelaar. Achtergronddocument bij Natuurverkenning 2011.

272 *Voorn G.A.K. van & D.J.J. Walvoort.* Evaluation of an evaluation list for model complexity.

273 *Heide, C.M. van der & F.J. Sijtsma.* Maatschappelijke waardering van ecosysteemdiensten; een handreiking voor publieke besluitvorming. Achtergronddocument bij Natuurverkenning 2011

274 *Overbeek, M.M.M., B. Harms & S.W.K. van den Burg* ***(2012)***. Internationale bedrijven duurzaam aan de slag met natuur en biodiversiteit.; voorstudie bij de Balans van de Leefomgeving 2012.

275 *Os, J. van; T.J.A. Gies; H.S.D. Naeff; L.J.J Jeurissen.* Emissieregistratie van landbouwbedrijven; verbeteringen met behulp van het Geografisch Informatiesysteem Agrarische Bedrijven.

276 *Walsum, P.E.V. van & A.A. Veldhuizen.* MetaSWAP_V7_2_0; Rapportage van activiteiten ten behoeve van certificering met Status A.

277 *Kooten T. van & S.T. Glorius.* Modeling the future of het North Sea. An evaluation of quantitative tools available to explore policy, space use and planning options.

279 *Bilt, W.G.M. van der, B. de Knegt, A. van Hinsberg & J. Clement* ***(2012).*** Van visie tot kaartbeeld; de kijkrichtingen ruimtelijk uitgewerkt. Achtergronddocument bij Natuurverkenning 2011

280 *Kistenkas, F.H. & W. Nieuwenhuizen.* Rechtsontwikkelingen landschapsbeleid: landschapsrecht in wording. Bijlage bij WOt-paper 12 – 'Recht versus beleid'

281 *Meeuwsen, H.A.M. & R. Jochem.* Openheid van het landschap; Berekeningen met het model ViewScape.

282 *Dobben, H.F. van.* Naar eenvoudige dosis-effectrelaties tussen natuur en milieucondities; een toetsing van de mogelijkheden van de Natuurplanner.

283 *Gaaff, A.* Raming van de budgetten voor natuur op langere termijn; Achtergronddocument bij Natuurverkenning 2011.

285 *Vries, P. de, J.E. Tamis, J.T. van der Wal, R.G. Jak, D.M.E. Slijkerman and J.H.M. Schobben.* Scaling human-induced pressures to population level impacts in the marine environment; implementation of the prototype CUMULEO-RAM model.

2012

286 *Keizer-Vlek, H.E. & P.F.M. Verdonschot.* Bruikbaarheid van SNL-monitoringgegevens voor EC-rapportage voor Natura 2000-gebieden; Tweede fase: aquatische habitattypen.

287 *Oenema, J., H.F.M. Aarts, D.W. Bussink, R.H.E.M. Geerts, J.C. van Middelkoop, J. van Middelaar, J.W. Reijs & O. Oenema.* Variatie in fosfaatopbrengst van grasland op praktijkbedrijven en mogelijke implicaties voor fosfaatgebruiksnormen.

288 *Troost, K., D. van de Ende, M. Tangelder & T.J.W. Ysebaert.* Biodiversity in a changing Oosterschelde: from past to present

289 *Jaarrapportage 2011.* WOT-04-001 – Koepel

290 *Jaarrapportage 2011.* WOT-04-008 – Agromilieu

291 *Jaarrapportage 2011.* WOT-04-009 – Natuur, Landschap en Platteland

292 *Jaarrapportage 2011.* WOT-04-010 – Balans van de Leefomgeving

293 *Jaarrapportage 2011.* WOT-04-011 – Natuurverkenning

294 *Bruggen, C. van, C.M. Groenestein, B.J. de Haan, M.W. Hoogeveen, J.F.M. Huijsmans, S.M. van der Sluis & G.L. Velthof.* Ammoniakemissie uit dierlijke mest en kunstmest in 2010; berekeningen met het Nationaal Emissiemodel voor Ammoniak (NEMA).

295 *Spijker, J.H., H. Kramer, J.J. de Jong & B.G. Heusinkveld.* Verkenning van de rol van (openbaar) groen op wijk- en buurtniveau op het hitte-eilandeffect

296 *Haas, W. de, C.B.E.M. Aalbers, J. Kruit, R.C.M. Arnouts & J. Kempenaar.* Parknatuur; over de kijkrichtingen beleefbare natuur en inpasbare natuur

297 *Doorn, A.M. van & R.A. Smidt.* Staltypen nabij Natura 2000-gebieden.

298 *Luesink, H.H., A. Schouten, P.W. Blokland & M.W. Hoogeveen.* Ruimtelijke verdeling ammoniakemissies van beweiden en van aanwenden van mest uit de landbouw.

299 *Meulenkamp, W.J.H. & T.J.A. Gies.* Effect maatregelen reconstructie zandgebieden; pilotgemeente Gemert-Bakel.

300 *Beukers, R. & B. Harms.* Meerwaarde van certificeringsschema's in visserij en aquacultuur om bij te dragen aan het behoud van biodiversiteit

301 *Broekmeyer, M.E.A., H.P.J. Huiskens, S.M. Hennekens, A. de Jong, M.H. Storm & B. Vanmeulebrouk.* Gebruikers-handleiding Audittrail Natura 2000.

302 *Bruggen van, C., C.M. Groenestein, B.J. de Haan, M.W. Hoogeveen, J.F.M. Huijsmans, S.M. van der Sluis & G.L. Velthof.* Ammonia emissions from animal manure and inorganic fertilisers in 2009. Calculated with the Dutch National Emissions Model for Ammonia (NEMA)

303 *Donders, J.L.M. & C.M. Goossen. Recreatie in groen blauwe gebieden.* Analyse data Continu Vrijetijdsonderzoek: bezoek, leeftijd, stedelijkheidsgraad en activiteiten van recreanten

304 *Boesten, J.J.T.I. & M.M.S. ter Horst.* Manual of PEARLNEQ v5

305 *Reijnen, M.J.S.M., R. Pouwels, J. Clement, M. van Esbroek, A. van Hinsberg, H. Kuipers & M. van Eupen.* EHS Doelrealisatiegraadmeter voor de Ecologische Hoofdstructuur. Natuurkwaliteit van landecosysteemtypen op lokale schaal.

306 *Arnouts, R.C.M., D.A. Kamphorst, B.J.M. Arts & J.P.M. van Tatenhove.* Innovatieve governance voor het groene domein. Governance-arrangementen voor vermaatschap-pelijking van het natuurbeleid en verduurzaming van de koffieketen.

307 *Kruseman, G., H. Luesink, P.W. Blokland, M. Hoogeveen & T. de Koeijer.* MAMBO 2.x. Design principles, model, structure and data use

308 *Koeijer de, T., G. Kruseman, P.W. Blokland, M. Hoogeveen & H. Luesink.* MAMBO visie en strategisch plan 2012-2015

309 *Verburg, R.W.* Methoden om kennis voor integrale beleidsanalysen te combineren.