# MAMBO

Design principles, model structure and data use

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MAMBO; Design principles, model structure and data use

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# 1. Introduction and objective

## 1.1 Introduction

At the beginning of the Eighties, LEI started with the development of the Manure model. Since 1989 MestAmm and since 1997 MAM. Problems 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 extensively used for the evaluation of policy measures and to monitor the manure streams and the emission of ammonia.

Due to technical limitations of the old model and difficulties to incorporate significant changes in policy measures, it was decided to develop a new manure model. This report gives an overview of all important elements of this new model.

## 1.2 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.

## 1.3 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. Chapter 8 describes the important aspects of the quality control of the model. The report ends with some final remarks and future developments.

Readers who are interested in a general overview of the model can focus on chapter 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 can also read chapters 5 and 6. Table 1.1 gives an overview of the information questions and the chapters to read.

*Table 1.1 advise to the reader*

| Information question | Chapters to read |
|---|---|
| What are the main ideas of the model? | Chapter 2, 4 |
| How does the model calculate in detail? | Chapters 4 and 5 |
| What can I do with the model? | Chapter 7 and 3 |
| Based on which data are the calculations made? | Chapter 6 |

# 2 Manure and minerals: a historical perspective

## 2.1 Introduction

Animal production has been related to environmental issues since a long time. Eutrophication (pollution of surface and ground water with nitrogen and phosphate), 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 history of the manure models, the predecessors of the model described in this report.

## 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 of pig and poultry farms without own land, stimulated the development towards manure production exceeding manure demand by crops. 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 is now to reach a balanced manure market in 2015. One way to achieve this aim was to reduce the manure production capacity. As a result, the government bought up manure production rights

In later years, also European legislation had a big impact on the manure policies. The European Nitrate Directive (91/676/EEC) states that member states must monitor all waters and identify zones vulnerable to agricultural nitrate leaching. A code of good agricultural practice had to  be established and an action program concerning the vulnerable zones must be formulated and contain restrictions on manure application (Frederiksen, 1994). The Netherlands have been monitoring groundwater bodies for years, and an increasing number of extraction points exceeded the allowed 50 mg of NO3 (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. Instead 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 4.1 gives a graphical overview of the system.

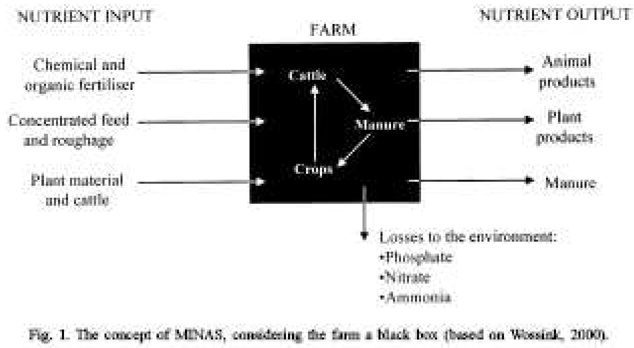


*Figure 4.1 The concept of MINAS, considering the farm a black box (based on Wossink, 2000).*

Only nitrogen and phosphorus entering (input) and leaving (output) the farm through the farm gate was taken into account, while the farm itself was considered as a black box. The difference between inputs and outputs is called the farm surplus and 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 individual 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.

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 was that MINAS was based on norms of mineral losses and that had to be application norms. Therefore a new nutrient policy measure of use has come into effect in 2006 to comply with the European Nitrate Directive. In this new policy Dutch farmers will have to comply with maximum use standards for different types of fertilizer. There are three use standards: (1) for the total volume of animal manure; (2) total working nitrogen application; and (3) total phosphate application.

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

The nitrogen use standard for total nitrogen application concerns the sum of chemical nitrogen fertilizer and working nitrogen in animal manure and working nitrogen in other organic fertilizers. The standard differs per crop. The phosphate use 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 use standards will be gradually reduced over the coming years.

This system of use standards in the Netherlands replaces the system of loss standards (i.e. MINAS). This means that farms are no longer assessed on the amount of nitrogen discharged (lost) into the environment (output), but on the amount of nitrogen they use for growing crops (input). The down side is that farms are less able to tailor their management systems to meet the environmental objectives.

*Ammonia emissions*

In 2001, the Netherlands agreed to comply with emission ceilings for sulphur dioxide (SO2), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOC) and ammonia (NH3) under the European 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) is very important to the Netherlands because it 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 NO2) 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 MNP (Dutch Environmental Assessment Agency) forecasts emissions of 126 kilo tonnes in 2010. Measures are being taken to cut ammonia emissions. One example is the dairy sector's urea target of 20 mg per liter of milk by 2010. Another important measure is the use of emission low housing systems. The same reduction can also be achieved with air scrubbers. 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 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 History of the manure model

Already in 1982 LEI started with the constructing 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 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 (Groenwold et al., 2002; Helming et al., 2005).

Late 2004, LEI started with the third generation of the manure and ammonia model for policy support (MAMBO). This generation was finished in 2007. It allowed the scientific decoupling of emission data and their origin, thus allowing the calculation of the national emission values using local originated data.

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 working group EAGER.

# 3. Design principles, assumptions and demarcation

## 3.1 Introduction

This chapter explains the background of the new mineral flow and emissions from agriculture model. 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 modeling at LEI for policy assessment was described in detail in Chapter 2. The previous MAM model has been successfully applied 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, the data output etc.

## 3.2 Objectives of the revision of the 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.

**Consistency with other models**

Within the LEI other models are available to evaluate agricultural and environmental policies. Microwave is a model framework, which supports the development of a range of models on a micro-economic level. One of the models in this framework is for example the financial economic simulation model (FES). Microwave takes a broad definition of a firm. A firm consists of one or more households and one or more establishments at different locations. An establishment can consist of one or more agricultural activities (departments).

To allow the integration of MAMBO with the general model framework MICROWAVE a similar definition of certain concepts such as a firm is used. Other concepts, such as Department, have been further specified for the specific requirements of MAMBO. In MAMBO a department can consist of a type of animals being kept at a farm (or establishment of a farm) or of a type of crop on which minerals could potentially be applied.

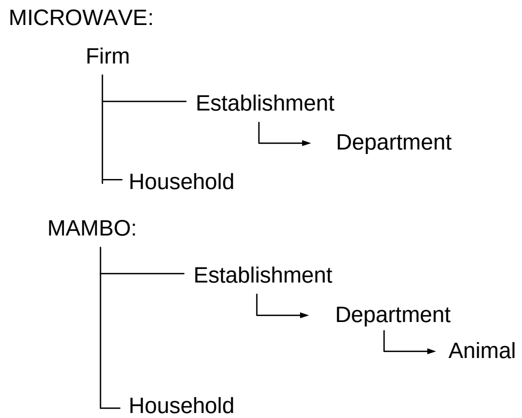


*Figure 3.1 Concepts in MAMBO and MICROWAVE*

Consistency with other models is achieved by using the same modeling 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 modeling 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.

### 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 modeling 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.

### 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.

### Model 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 it 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.

### Model 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 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 modeled in MAMBO. MAMBO makes use of the outcomes of such zootechnical 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 modeled 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 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).

In the current version the common element linking different procedures and modules within the modeling framework is manure quantity (demarcation number 1 in section 3.4). This manure quantity can have mineral contents and this content can change (be updated in the course of the model due to losses and emissions).

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.

Exogenous manure price. Price of manure is determined outside of the model. Other models of the LEI provide the possibility to model the manure price as an endogenous variable. Based on the market conditions of supply and demand for manure and minerals a price for manure is determined. In scenarios of MAMBO information from other models on the manure price can be used.

# 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 chapter 5 and 6.

## 4.2 Conceptual model

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 next part of this chapter.

**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.

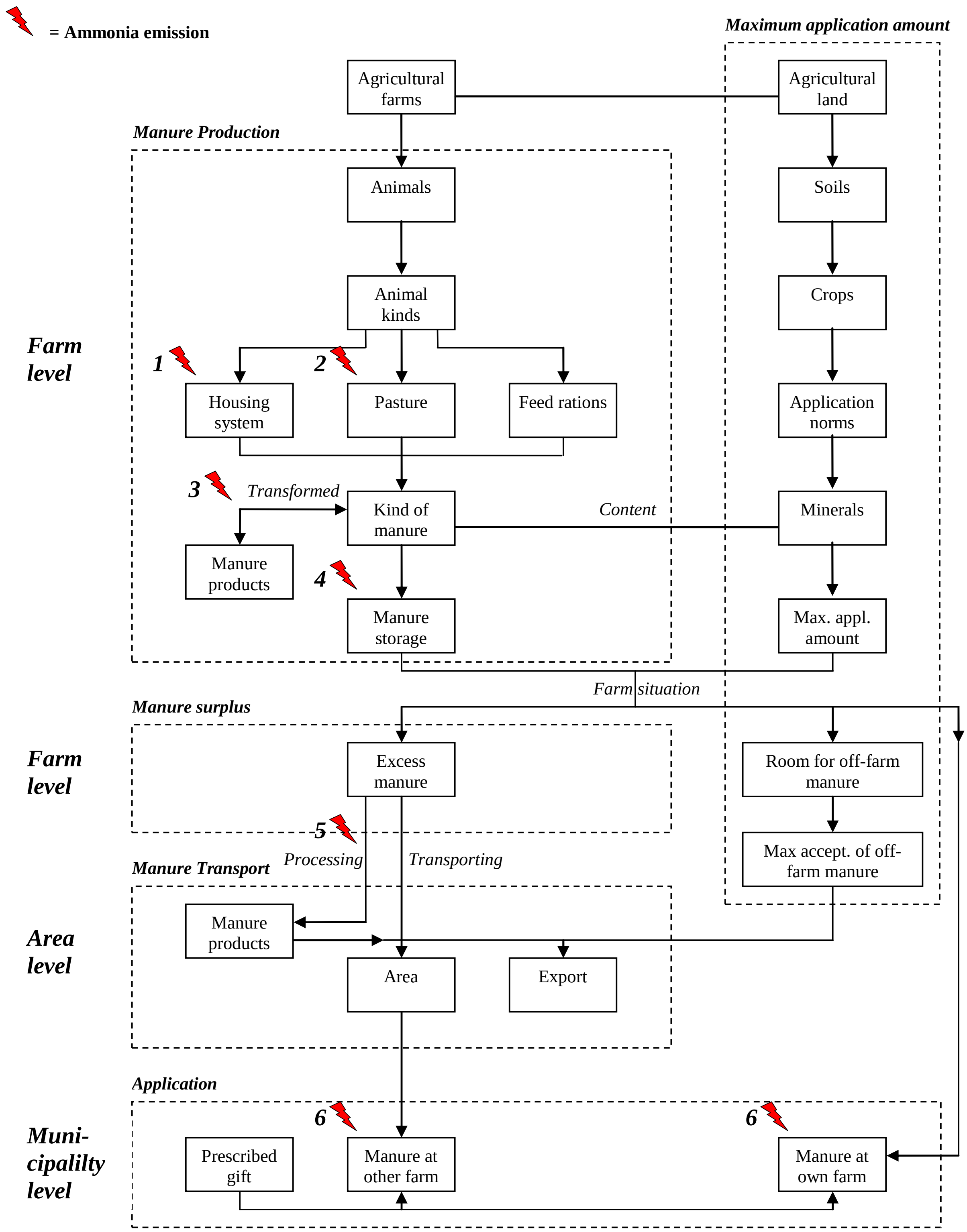


*Figure 4.1. The Manure and Ammonia emission Model (MAM/MAMBO).*

**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.

**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.

**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.

**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. The computational model is documented elsewhere (Kruseman, Mokveld and Bouma, 2007). 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 (see 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 (see Table 5.2) and the second to levels of aggregation (see 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 ($d^p$), pasture manure categories ($f^{pm}$) 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 |
|---|---|---|---|
| $\alpha$ | 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) | | variable1 |
| m | Municipality in Regional area | | variable2 |
| n | Region in Country | N | {R1,R2} |
| p | Province in region | | {P1*P12} |

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.

| | | | |
|---|---|---|---|
| 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) | | |

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 |
| 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>} |
| $\mu$ | | manure aspect type | {slurry,water,ashes,solid} |
| $\omega$ | | manure process | variable |
| $\rho$ | | ration factors | variable |
| $\varphi$ | | Emission factors | {$NH_3$} |
| $\sigma$ | | Source (of manure) | {own, off-farm} |
| | $\sigma^{own}$ | 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** |
|---|---|---|
| $\Theta$ | | 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) |
| $\Omega$ | | relational mapping (context specific) |
| | $\Omega_{\delta \mid h}$ | derogation to firm mapping |
| $\Phi$ | | 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 (see 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** |
|---|---|---|---|
| $\alpha$ | acceptation degrees | c | dimensionless |
| $\varepsilon$ | Emission coefficient | | |
| $\varepsilon^{stable}$ | 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 |
| $\mu$ | Mineral content of fertilizers | m,f | Kg minerals per kg manure |
| $\nu$ | Excretion volume | ρ,a | Kg Manure per animal |
| $\pi^{manure\ revenue}$ | manure revenue: benefits of accepting off-farm manure | f | Euro per kg manure |
| $\rho$ | Ration factor, proportion of a ration in the overall feed strategy of the animal category | ρ,a | dimensionless |
| $\tau$ | 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 | | dimensionless |

| | | | |
|---|---|---|---|
| | deviation from legal fertilization norms | | |
| 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, 2006)). 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. Alternative procedures can be envisaged in the future 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 7 parts with in total 17 subparts which we call 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.
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 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 II)*

| **Part** | **Model phase** | **Module** Name of GAMS model | **When used** | **Section** where it is described |
|---|---|---|---|---|
| I. Preparation | Data preparation | - GetMamboData | Start of project | 6.# |
| II. Manure Production Calculations | Data change prior to basic manure production calculations | - AnimalNumbersSA<br>- CropAreaSA<br>- FertilizerMineral ContentSA<br>- FixFertMineral ContentSA<br>- MinimalFertilizer ApplicationSA<br>- UreaContentSA | Scenario specific | 6.# |
| | Precompilers related to basic manure production calculations | - PreCompiler<br>- PasturePrecompiler<br>- InternalManure Standard | always | |
| | basic manure production calculations | - MAMBOBMPC | Always | 5.4, 5.5 |

In table 5.7b we present the structure of part III of MAMBO. In this part the model phases are similar in type to the ones described in part II. In part III 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 III)*

| | | | | |
|---|---|---|---|---|
| III. 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 | 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 is 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).

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.

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

*Table 5.7c Structure of modular approach (part IV-V)*

| | | | | |
|---|---|---|---|---|
| IV. Manure placement on firm | Data change prior to Manure placement on firm | <none> | Scenario specific | |
| | Precompilers related to manure placement on firm | - ExtManureCatSpecCalc<br>- PasturePrecompiler<br>- RegionalAreaInfo<br>- MinCropFertilizerCapacity<br>- SortCropMinimumMineralCapacity<br>- LocalSets | Always | |
| | Firm model | - Rule-based Firm model | Always | 5.7 |
| V. Spatial equilibrium model for distribution of surplus manure | Data change prior to spatial equilibrium model | - ManureExportSA<br>- ManureProcessSA<br>- AcceptationDegreeSA | Scenario specific | |
| | Precompilers related to spatial equilibrium model | - DataPrepare<br>- CropClassFertClassRequirementCalc<br>- | Always | |
| | spatial equilibrium model | - Transport model | Always | 5.8 |

*Table 5.7d Structure of modular approach (part VI-VII)*

| | | | | |
|---|---|---|---|---|
| VI. 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 | - FixMineralContentCorrection | Always | |
| | fertilizer application calculations | - FAModel | Always | 5.9 |
| VII. Reporting results | Report writing | - Report | Always | |

## 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 ($\rho$) the animals are fed, the excretion volume ($v$) 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 ($\tau$) 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.

$$B_{\rho da}^{manure} = N_{da}^{animals} * \rho_{\rho a} * v_{\rho a} * \tau_{\rho da} \qquad (1)$$

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.

$$B_{\rho daf}^{manure} \Leftrightarrow B_{\rho da}^{manure} \qquad (2)$$

Mineral production ($M^{animal}$) of an animal in a department for a manure category depends on the mineral content of the manure excreted ($\mu$). 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.

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

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:

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

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

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

$$D_u^{lb} < u^{milk} < D_u^{ub} \quad (4)$$

$$D_{q^{milk}}^{lb} < Q^{milk} < D_{q^{milk}}^{ub} \quad (5)$$

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 ($\varepsilon^{stable}$). Hence, the mineral emissions (E) from the animal manure inside the animal house and from grazing are expressed separately in equations 6 and 7. 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).

$$E_{\varphi md^s af}^{stable} = M_{md^s af}^{manure,scientific} * \varepsilon_{\varphi md^s f}^{stable} \quad \text{(6, flag 1 in Figure 4.1)}$$

$$E_{\varphi md^p af}^{pasture} = M_{md^p af}^{manure,scientific} * \varepsilon_{\varphi md^p f}^{pasture} \quad \text{(7, flag 2 in Figure 4.1)}$$

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 6.

$$M_{mdaf}^{manure,scientific,after\,emissions} = M_{mdaf}^{manure,scientific} - \sum_{\varphi} \left( E_{\varphi mdaf}^{pasture} + E_{\varphi mdaf}^{stable} \right) \quad (8)$$

**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.

$$E_{mdfo}^{storage} = s_{do} * \varepsilon_{\varphi do}^{storage} * \sum_{a} M_{mdaf}^{manure,scientific,after\,emissions} \qquad \text{(9, flag 4 in Figure 4.1)}$$

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 10, the emissions from processing depend on the amount of manure processed, the mineral content of that manure and the way of processing.

$$E_{\varphi\rightarrow\phi,M\varepsilon}^{process} = \varepsilon_{\varphi\rightarrow\phi,M\varepsilon}^{process} * \sum_{Rrm} \left( \mu_{M\varphi} * \sum_{FE} \left( Q_{FERrm,\varphi}^{process} \right) * R_{Rrm,\varphi,M}^{average} \right) \qquad \text{(10, flag 5 in Figure 4.1)}$$

**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 11a.
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 12a.

$$M_{m}^{Max\,allowable,crops} \leq \sum_{sc} \left( \sum_{\delta} \left( D_{\delta}^{derogation} * l_{m\delta c}^{m} \right) * A_{sc}^{crops} * \left( 1 + l^{allowance} \right) \right) \qquad \text{(11a)}$$

$$M_{mf}^{Max\,allowable,crops} \leq \sum_{sc} \left( \sum_{\delta\sigma^{own}} \left( D_{\delta}^{derogation} * \left[ \frac{\left( l_{m\delta sc|r}^{f} - e_{mc}^{Min\,application} \right)}{\gamma_{m\sigma^{own} scf|n}^{Min\,effect\,coef}} \right] \right) * A_{sc}^{crops} * \left( 1 + l^{allowance} \right) \right) \qquad \text{(12a)}$$

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 13a)3.

$$M_{m}^{Actual,crops} = \sum_{ad^{s}f}\left(M_{md^{s}af}^{manure,\,fixed}\right) \qquad (13a)$$

Alternatively it can be calculated over the scientific knowledge-based mineral production of stable manure (equation 13b)4.

$$M_{m}^{Actual,crops} = \sum_{ad^{s}f}\left(M_{md^{s}af}^{manure,scientific}\right) \qquad (13b)$$

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

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.

$$\min B_{daf}^{manure,surplus} = B_{daf}^{manure} - B_{daf}^{manure,applied\ own\ farm} \qquad (14)$$

In order to abide by the constraint presented in equation 12a and 12b the following equation can be derived:

$$\sum_{\delta}\left(D_{\delta}^{derogation} * l_{m\delta c}^{m}\right) * A_{scdf}^{crops\ with\ own\ manure} * \left(1 + l^{allowance}\right) \geq I_{dfsc}^{own\ manure,applied\ own\ crops} * \left[\frac{\sum_{a} M_{mdaf}^{manure,\,fixed}}{\sum_{a} B_{daf}^{manure}}\right] \qquad (15)$$

where

$$\sum_{sc} I_{dfsc}^{own\ manure,applied\ own\ crops} = \sum_{a} B_{daf}^{manure,applied\ own\ farm} \qquad (16)$$

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.

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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.

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 the do not have sufficient amounts. In both cases trading is costly and include the opportunity costs of not applying the manure on the own famr.

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

$$\sum_{\delta\sigma^{own}} \left( D_{\delta}^{derogation} * \left[ \frac{\left( l_{m\delta sc|r}^{f} - e_{mc}^{Min\,application} \right)}{\gamma_{m\sigma^{own} scf|n}^{Min\,effect\,coef}} \right] \right) * A_{scdf}^{crops\,with\,own\,manure} * \left( 1 + l^{allowance} \right) \geq B_{dfsc}^{own\,manure,\,applied\,own\,crops} * \left[ \frac{\sum_{a} M_{mdaf}^{manure,\,fixed}}{\sum_{a} B_{daf}^{manure}} \right] \tag{17}$$

We also define a manure volume balance (equation 19) and a cropped area balance (equation 18):

$$A_{sc}^{crops} \geq \sum_{df} \left( A_{scdf}^{crops\,with\,own\,manure} \right) \tag{18}$$

$$\sum_{a} B_{d^{p}af}^{manure} = \sum_{sc} \left( B_{d^{p}fsc}^{own\,manure,\,applied\,own\,crops} \right) \tag{19a}$$

$$\sum_{a} B_{d^{s}af}^{manure} \geq \sum_{sc} \left( B_{d^{s}fsc}^{own\,manure,\,applied\,own\,crops} \right) \tag{19b}$$

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 5.1), equation 19a 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:

$$B_{daf}^{manure,\,surplus} = 0 \tag{20}$$

and

$$A_{sc}^{crops} - \sum_{df} \left( A_{scdf}^{crops\,with\,own\,manure} \right) \neq 0 \tag{21}$$

The objective function becomes:

$$\max A_{scdf}^{crops\,with\,own\,manure} \tag{22}$$

for the crop with first preference for manure, given constraint equations 15-19, and abiding by non-negativity constraints and rules regarding allowed crop fertilizer combinations. If equation 20 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.

### 5.7 Distribution of surplus manure using a spatial equilibrium model

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.*, 2001).

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.

$$B_{df|r}^{manure,surplus} + B_{df|r,t-1}^{Storage} = \sum_{R} B_{df|r \to R}^{manure,transported} + \sum_{\omega} B_{df\omega|r}^{manure,\,processed} + B_{df|r}^{manure,Exported} + B_{df|r}^{Storage} \tag{23}$$

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.

$$\sum_{\omega}\left(\varphi_{dfDF\omega}^{proceesed\ manure\ fraction} * B_{df\omega|r}^{manure,\ processed}\right) = QB_{DF|r}^{manure\ product,Exported} + B_{DF|r}^{manure\ product,Dumped} + \sum_{R} Q_{DF|r\rightarrow R}^{manure\ product,Transported} \quad (24$$

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 ($\alpha_c$) 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.

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

$$Q_{df|r\rightarrow R}^{manure\ product,transported} * \left[\frac{M_{mdf|r}^{manure\ product,scientific}}{\left(Q_{df|r}^{manure\ product,Exported} + Q_{df|r}^{manure\ product,Dumped} + Q_{df|r\rightarrow R}^{manure\ product,Transported}\right)}\right] + B_{df|r\rightarrow R}^{manure,transported} * \left[\frac{\sum_a M_{mdaf|r}^{manure,scientific}}{\sum_a B_{daf|r}^{manure}}\right] \quad (25)$$

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

$$M_{mdf|r}^{manure\ product,scientific} = \sum_{DF\omega} \varphi_{mDFdf\omega}^{Mineral\ distribution\ fraction} * B_{DF\omega|r}^{manure,\ processed} * \frac{\sum_a M_{mDaF|r}^{manure,scientific}}{\sum_a B_{DaF|r}^{manure}} \quad (26)$$

The left-hand side of equation 25 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:

$$\min C^{AggregateCost} - \Pi^{Aggregate\ revenues} \quad (27)$$

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

$$C^{AggregateCosts} = \sum_{df} \left( \begin{array}{l} \sum_{r\to R|r=R} \left( \sum_{\mu\in M\mu f} \left( \left( c_{\mu}^{fixed,in\,r} + c_{\mu}^{storage,in\,r} + \sum_{\sigma^{offfarm}} c_{\sigma^{offfarm} f}^{application} \right) * \left( B_{df|r\to R}^{manure,transported} + Q_{df|r\to R}^{manure\ product,transported} \right) \right) \right) + \\ \sum_{r\to R|r\neq R} \left( \sum_{\mu\in M\mu f} \left( \left( \begin{array}{l} c_{\mu}^{transport} * d_{r\to R} + \\ c_{\mu}^{fixed,out\,r} + c_{\mu}^{storage,out\,r} + \sum_{\sigma^{offfarm}} c_{\sigma^{offfarm} f}^{application} \end{array} \right) * \left( B_{df|r\to R}^{manure,transported} + Q_{df|r\to R}^{manure\ product,transported} \right) \right) \right) + \\ \sum_{\omega|r} \left( \left( \sum_{\mu\in M\mu f} \left( c_{\mu}^{storage,\ processed\ manure} + c_{\mu}^{fixed,\ Sector} \right) + c_{\omega f}^{process} \right) * B_{df\omega|r}^{manure,\ processed} \right) \\ \sum_{r} \left( \sum_{\mu\in M\mu f} \left( c_{\mu}^{fixed,\ Export} * \left( B_{df|r}^{manure,\ Exported} + Q_{df|r}^{manure\ product,\ Exported} \right) \right) \right) + \\ \sum_{sc} \left( c_{scdf}^{risk\ penalty} * I_{scdf|R}^{crops\ with\ offfarm\ manure} \right) \end{array} \right) \quad (28)$$

and

$$\Pi^{Aggregate\,revenues} = \sum_{r\to R,r=R} \left( \pi_{fR}^{manure\,revenue} \left[ B_{df|r\to R}^{manure,transported} + Q_{df|r\to R}^{manure\ product,transported} \right] \right) \quad (29)$$

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 (see Figure 5.2):

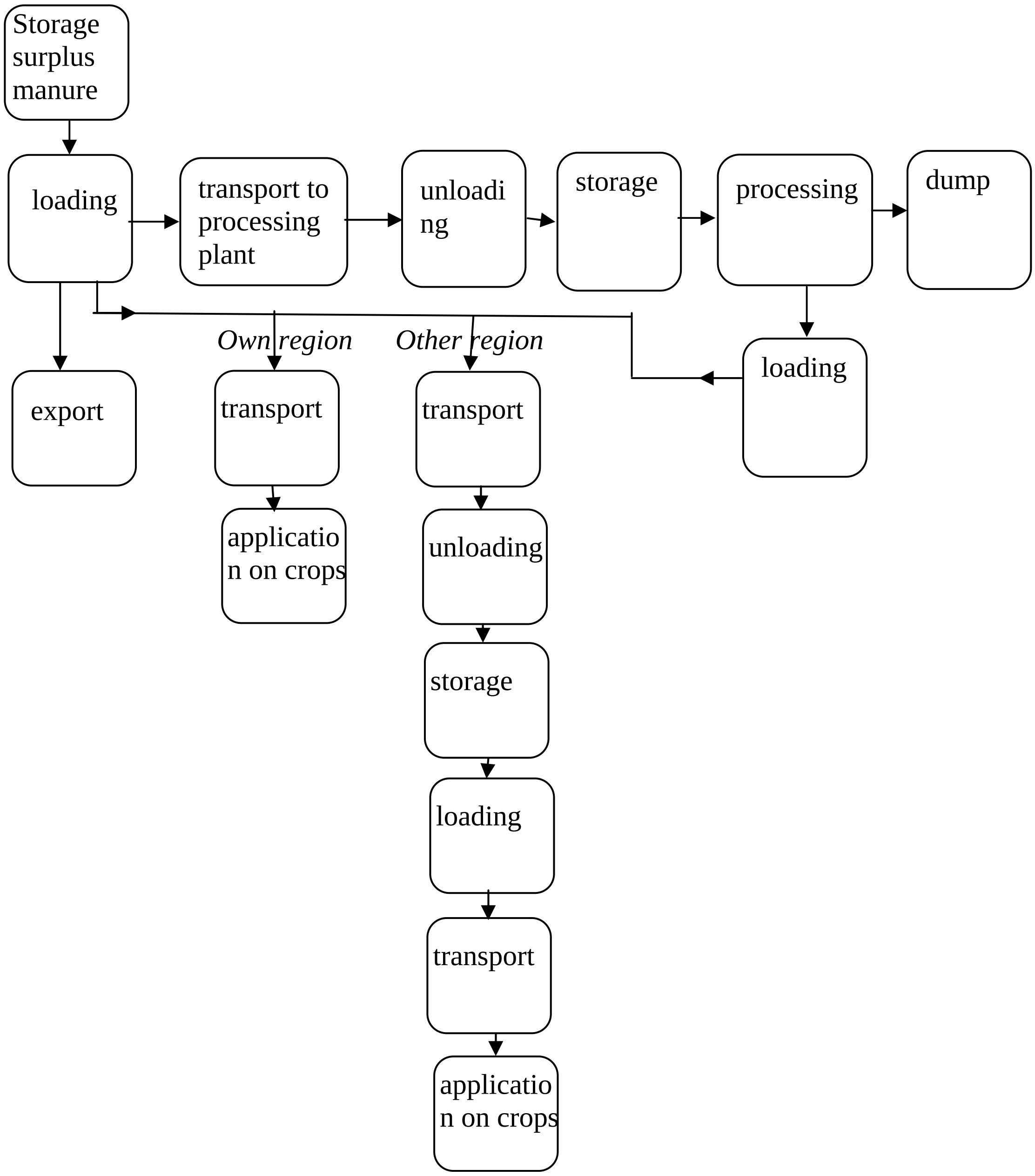



Figure 5.2 Manure Transport Activities

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.

*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 moineral 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).

$$A_{\delta sc|m}^{crops,not\ fertilized} = A_{\delta sc|m}^{crops} - \sum_{df} \left( A_{scdf|m}^{crops\ with\ own\ manure} + A_{scdf|m}^{crops\ with\ offfarm\ manure} + A_{scdf|m}^{crops\ with\ manure\ products} \right) \quad (30)$$

$$\sum_{\delta\sigma^{offfarm}} \left( \left[ \frac{\left( l_{m\delta sc|R}^{f} \right)}{\gamma_{m\sigma^{offfarm}scf|m}^{Min\ effect\ coef}} \right] \right) * \left( \left[ A_{\delta sc|m}^{crops,not\ fertilized} \right] \right) * \left( 1 + l^{allowance} \right) \geq I_{\delta fsc|m}^{artificial\ fertilizer} * \mu_{mf} \quad (31)$$

With

$$e_{mc}^{Min\ application} \leq \frac{\sum_{f \in m} \left( I_{\delta fsc|m}^{artificial\ fertilizer} * \mu_{mf} \right)}{\sum_{f \in m} \left( A_{\delta fsc|m}^{artificial\ fertilizer} \right)} \quad (32)$$

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

$$E_{\varphi mscf|s}^{Organic\ application} = \left( \sum_{\kappa\delta\sigma\eta\mu} \left( \begin{array}{l} M_{m\delta\sigma fsc}^{Organic\ Minerals\ applied\ to\ crops} * \eta_{\eta\mu sc}^{application\ utilization} * \\ \varepsilon_{\varphi m\kappa\eta\mu}^{application} * \varphi_{m\kappa f}^{Mineral\ fraction} \end{array} \right) \right) * \gamma_{mcf|s}^{Mineral\ effect} * \varphi_{sc|s}^{season\ application} \qquad \mu \in \Phi_{\mu f},\ f \in \{ f^{m}, f^{mp} \} \quad \text{(33, flag 6 in Figure 4.1)}$$

For artificial (inorganic) fertilizers a different equation is used

$$E_{mscf^{a}|s}^{Inorganic\ application} = I_{\delta scf^{a}}^{Artificial\ fertilizer} * \mu_{mf^{a}} * \varepsilon_{mf^{a}}^{Artificial\ fertilizer} \quad \text{(34, flag 6 in Figure 4.1)}$$

**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 10b.

$$M_{m}^{Max\,allowable,\,pastures} \leq \sum_{sc^{p}} \left( \sum_{\delta} \left( D_{\delta}^{derogation} * l_{m\delta sc^{p}}^{m} \right) * A_{sc^{p}}^{pastures} * \left( 1 + l^{allowance} \right) \right) \tag{10b}$$

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 11b.

$$M_{mf}^{Max\,allowable,\,pastures} \leq \sum_{sc^{p}} \left( \sum_{\delta\sigma^{own}} \left( D_{\delta}^{derogation} * \left[ \frac{\left( l_{m\delta sc^{p}|r}^{f} - e_{mc^{p}}^{Min\,application} \right)}{\gamma_{m\sigma^{own} sc^{p} f|n}^{Min\,effect\,coef}} \right] \right) * A_{sc^{p}}^{pastures} * \left( 1 + l^{allowance} \right) \right) \tag{11b}$$

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 12c6.

$$M_{m}^{Actual,\,pasture,\,fixed} = \sum_{a^{g} d^{p} f} \left( M_{md^{p} a^{g} f}^{manure,\,fixed} \right) \tag{12c}$$

Alternatively it can be calculated over the scientific knowledge-based mineral production of grazing animals on pastures (equation 12d)7.

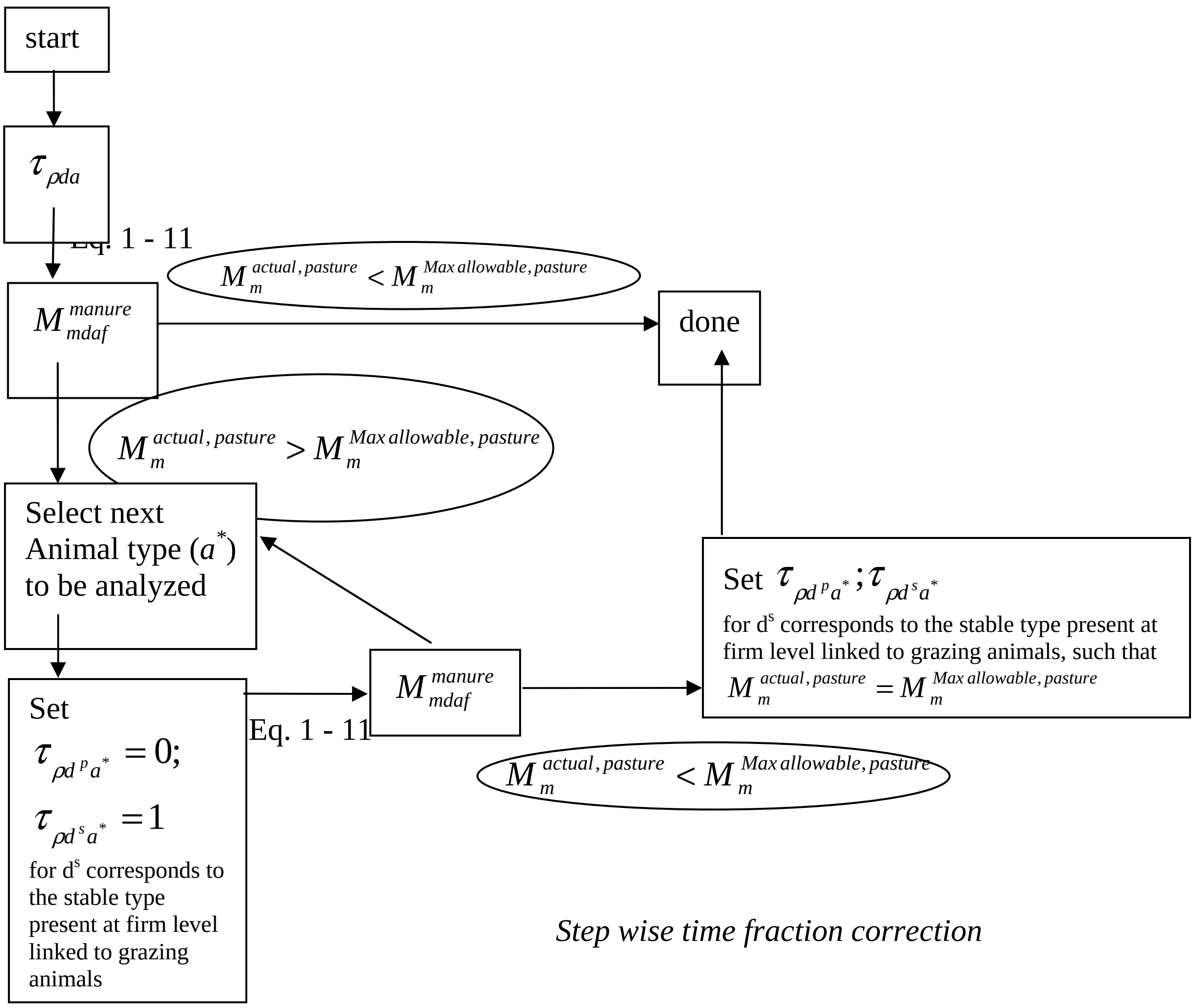
6 In the current situation in the Netherlands (*post* 2005 legislation) the amount of minerals the firm has to take into account are based on the legally fixed mineral contents after emissions

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

$$M_m^{Actual,pasture,scientific} = \sum_{a^g d^p f} \left( M_{md^p a^g f}^{manure,scientific} \right) \qquad (12d)$$

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.

Figure 5.1 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 the control variables are described that are used to define MAMBO.

## 6.2 Data elements in different parts of the model

This paragraph 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.

*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 a 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 et al, 2005) or APPROXI (Hennen et al, 1997) 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 (Cor 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 Agriculture, Nature and Food Quality (LNV). 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.

**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 (MNP). 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 at al (2000).

*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 et al, 2005) or APPROXI (Hennen et al, 1997) 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.

**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 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 (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 Agriculture 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.

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

*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 agriculture. 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 that are 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.

*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 Schroder et al (2004).

**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.

### 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.

### 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.

**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 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.

**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 agriculture (LNV-

DR) and they produce statistics at national and regional level. These data are also published on Statline, the online database of Statistics Netherlands (CBS).

**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, 2006).

*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.

**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).

**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.

**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 Agriculture are also published in the online database. The publication of this information is to late to use in the inventory studies, therefore the data for the inventory studies are directly received from the Ministry of Agriculture. Also the final information on the amount of manure processing is to 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.

**Research results of WUR**
*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.

**Research results Netherlands environmental assessment agency (MNP)**
*Data elements:*

- emission factors of housing, grazing, storage and application of manure

*Short description of source:*
The task of the Dutch Environmental Assessment Agency 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 will publish an update of the emission factors in 2008.

*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 | 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 | | |
| Transactiotn 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 | Unknown | Administrative | | Primary | None | |
| Manure excretion | WUM | Yearly | Emperical | Sample | Processed | | |
| Artificial fertilizer | LEI | Unknown | Emperical | | Processed | | |
| Transport, export and process manure | LNV-DR/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 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 | MAM<br>MAMBO<br>MAMBO2006 | 10<br>41<br>43 |

| | | | | |
|---|---|---|---|---|
| iAnimalClasses | a | aggregated animal categories used for reporting | MAMBO | 11 |
| iApplicationtype | | method for application of manure to fields | BASIS | 7 |
| iCountry | c | three letter acronym | BASIS | |
| iCropClasses | c | aggregated crop identifier | BASIS,MAM<br>STONE | 9<br>26 |
| iCrops | c | crop identifier | MAM<br>MAMBO<br>MAMBO2005a<br>MAMBO2005b | 9<br>95<br>111<br>174 |
| iDepartmentCategories | d | department categories | BASIS,MAM<br>MAMBO2006<br>STONE | 30<br>33<br>34 |
| iDerogation | d | derogation | BASIS | 2 |
| iDR_ManureCategories | | Manure categories of Dienst Regelingen | NLD/MAMBO2006 | 55 |
| iEmissionFactors | | Chemical composition of emitting minerals | BASIS | 4 |
| iFertClasses_Reports | | Aggregation of fertilizer classes | MAMBO | 6 |
| iFertDest_Sector | | Sectors for fertilizer transport destinations | BASIS | 3 |
| iFertDestination_RA | | Group of regional areas for fertilizer transport destinations | BASIS | 3 |
| iFertilizerCategories | f | Fertilizer categories | MAM<br>MAMBO<br>MAMBO2006 | 59<br>133<br>139 |
| iFertilizerClasses | | Aggregated fertilizer categories | MAM<br>STONE | 56<br>29 |
| iFirm | f | Firm identifier | NLD/BDL/YEAR/2002<br>NLD/BDL /YEAR/2004<br>NLD/BDL /YEAR/2006 | 89580<br>81830<br>79511 |
| iLinkClasses | | Classes to link DR_ManureCategories with FertilizerCategories | BASIS<br>MAMBO2006 | 26<br>27 |

| | | | | |
|---|---|---|---|---|
| iManureAspectType | | Characteristic of manure | BASIS | 5 |
| iManureFactoryCategory | | Factory types for manure processing | BASIS | 1 |
| iManureMarketRegions | | Aggregation of regional areas | BASIS | 11 |
| iManureProcess | | Types for processing manure | BASIS | 6 |
| iManureSource | | Origin of manure | BASIS | 2 |
| iManureStorageCat | | Types of manure storage | BASIS | 3 |
| iMilkQuantCategory | | Ranges of milk quantity | BASIS | 22 |
| iMineralFraction | | Fractions of minerals | BASIS | 4 |
| iMinerals | | Mineral identifier | BASIS | 3 |
| iMunicipalities | | Municipality identifier | NLD/YEAR/2002<br>NLD/YEAR/2005<br>NLD/YEAR/2006 | 490<br>467<br>458 |
| iProvince | | Province identifier | BASIS | 12 |
| iRations | | Ration identifier | BASIS<br>MAM | 21<br>10 |
| iRegionalAreas | | RegionalArea identifier | BASIS | 31 |
| iRegion | | Aggregation of regional areas | BASIS | 2 |
| iSeason | | Season identifier | BASIS | 4 |
| iSoilType | | Soil type identifier | BASIS<br>MAM<br>MAMBO2006<br>STONE | 7<br>7<br>4<br>7 |
| iUreumCategory | | Range of urea contents | 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 to 6.8 the control variables used in MAMBO are highlighted. For each control variable we provide a description, the values it takes on and the modules within MAMBO where they are active

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 } |

# 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*

| Output variable | Unit | Level of aggregation |
|---|---|---|
| Number of animals and hectares | Units and hectares | Farm level<br>National<br>31 manure regions<br>Other regional division |
| Production of manure | kg manure and minerals per type of manure | Farm level<br>National<br>31 manure regions<br>Other regional division |
| Farm surpluses | kg manure and minerals per type of manure | Farm level<br>National<br>31 manure regions<br>Other regional division |
| Hectares without application of manure | hectares | Farm level<br>National<br>31 manure regions<br>Other regional division |
| Destination of farm surpluses | kg manure and minerals | National<br>31 manure regions<br>Other regional division<br>Abroad |
| Ammonia emission animal | kg emission from housing | Grid 5 * 5 km |

| | | |
|---|---|---|
| manure and artificial fertilizer | /grazing/storage/ processing/application per type of manure | National<br>31 manure regions<br>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<br>National<br>31 manure regions<br>Other regional division |
| Application of artificial fertilizer in kg/ha | kg minerals per crop and soil type | National<br>Other regional division<br>31 manure regions |
| Transport of manure within, between regions and abroad | Kg of manure and distance | National<br>31 manure regions<br>Export |
| Processing | Kg of manure | National<br>31 manure regions |
| Costs and or earnings of manure distribution, processing and application | Euro's per kg of manure type | National<br>31 manure regions<br>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<br>31 manure regions<br>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 7.0 Allocation of 31 manure regions to non-concentration region, concentration region East and concentration region South.*

## 7.3 Applications of the MAMBO model

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, the yearly Dutch ammonia emission inventory is established in cooperation with the Dutch Environmental Assessment Agency (MNP), (MNP, 2006a). Paragraph 7.3.1 describes some results;
- Situation on the Dutch manure market: since 2006, the yearly situation on the Dutch manure market is established (Luesink at al, 2007b). Paragraph 7.3.2 gives some results of these studies;

Forecasting studies are for instance:

- prediction of the Dutch ammonia emission in 2010 (Hoogeveen at al, 2003);
- forecast studies of the Dutch manure situation (Staalduinen et al, 2002; De Hoop et al, 2004; Luesink et al, 2004a; Luesink et al, 2007a). Paragraph 7.3.3 gives a summery of the results of Luesink et al (2007 a);
- 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 at al, 2005 and 2007). Paragraph 7.3.4 gives some results of the last study.

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 at al, 2001).

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.

### 7.3.1 The yearly national 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., 2007; Luesink, 2004): 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. The data presented in this table are the official ammonia emissions of the Netherlands as reported to the European Union. 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, 2004b and Hoogeveen et al, 2007)*

| | 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 7.1 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.

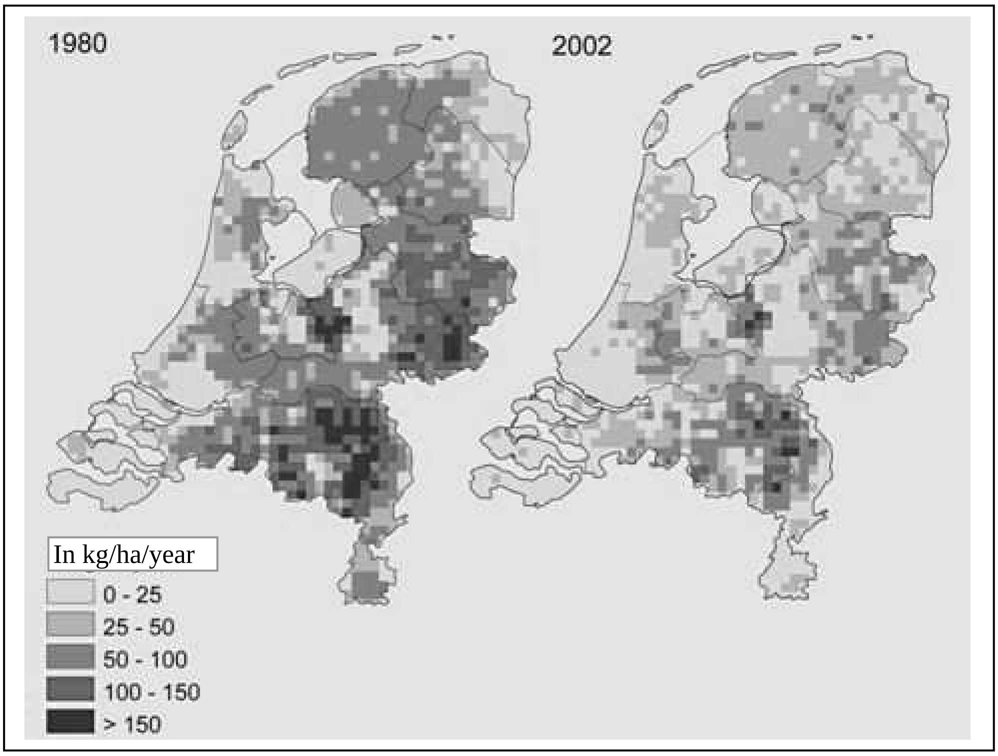



*Figure 7.1. Ammonia emission in the Netherlands in kg per ha per year in 1980 and 2002 (RIVM/CBS, 2004).*

### 7.3.2 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 paragraph a summary of the results of 2006 are described.

Figure 7.2 presents the results for the production of manure and figure 7.3 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.

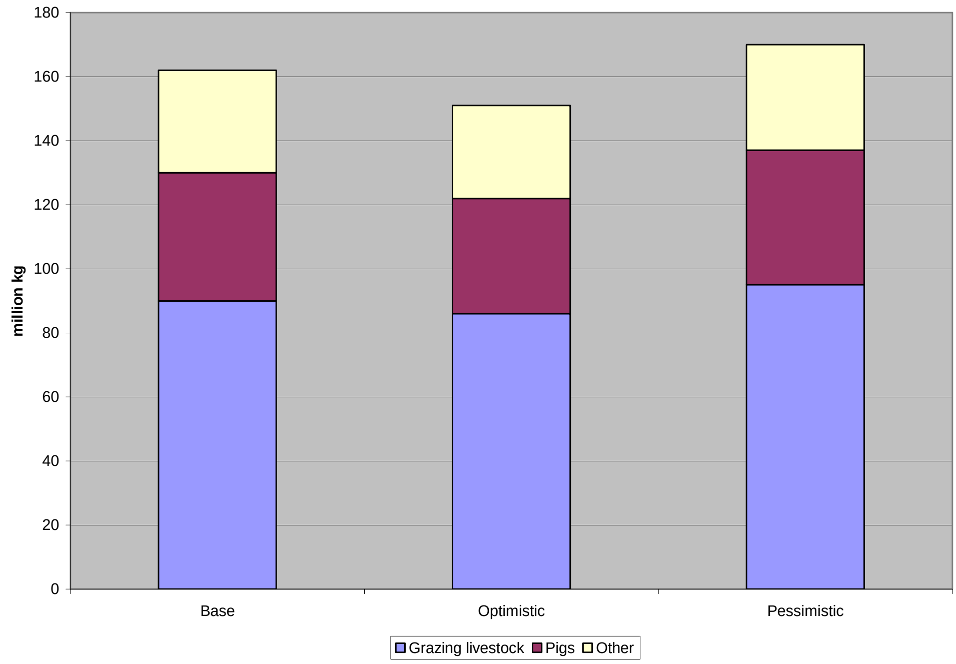



*Figure 7.2 Manure production (kg of phosphate) for the year 2006 according to 3 scenario's*

*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 (see figure 7.2). 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.

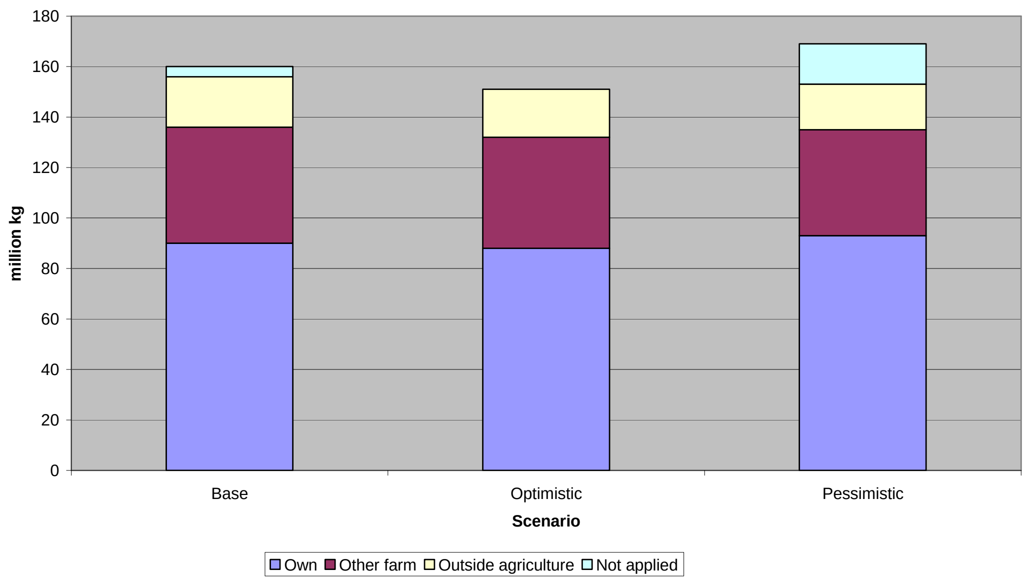



*Figure 7.3 Application of manure (million kg of phosphate) for the year 2006 according to 3 scenario's*

*Application of manure*
Figure 7.3 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.
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 7.3 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.

### 7.3.3 Results of the 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 agriculture 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 7.4 displays the predictions of the production of phosphate for four different years. Figure 7.5 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 7.5 is based on the results of scenario 1.

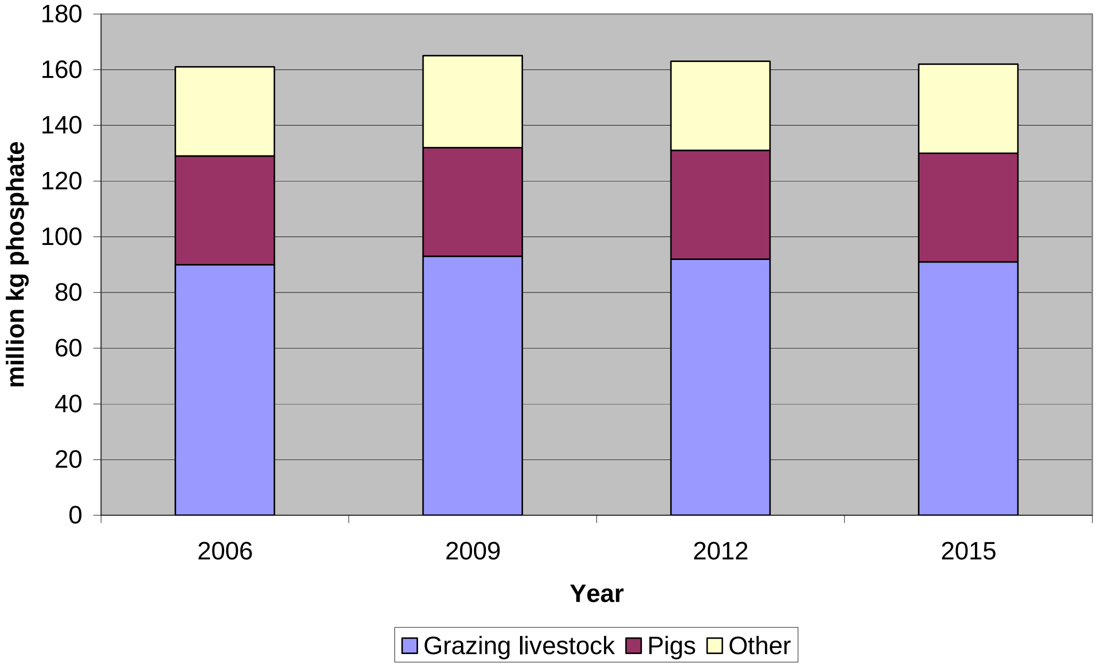


*Figure 7.4 Estimated production of phosphate in 4 different years*

*Production*
The estimated phosphate production for 2009 is slightly higher than for 2006 (see figure 7.4). 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.

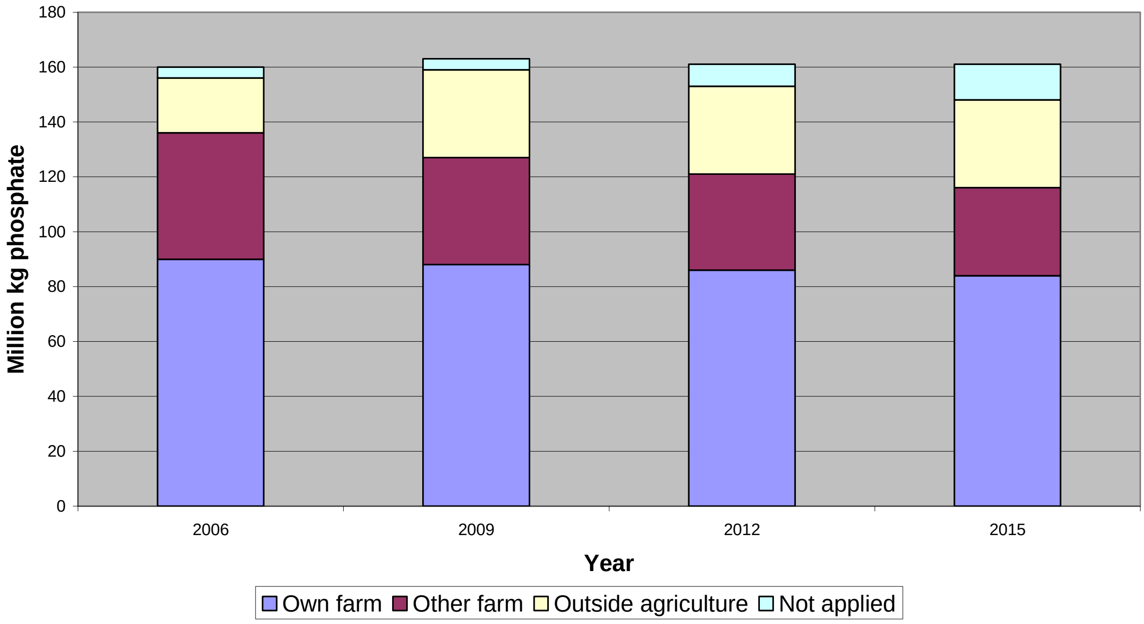



*Figure 7.5 Estimated application of phosphate (for the year 2006, 2009, 2012, 2015)*

*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 (see figure 7.5). 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).

### 7.3.4 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).

The figures 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 the figures refer to the following combinations of agricultural land use and scenario:

| 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 7.6 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%.

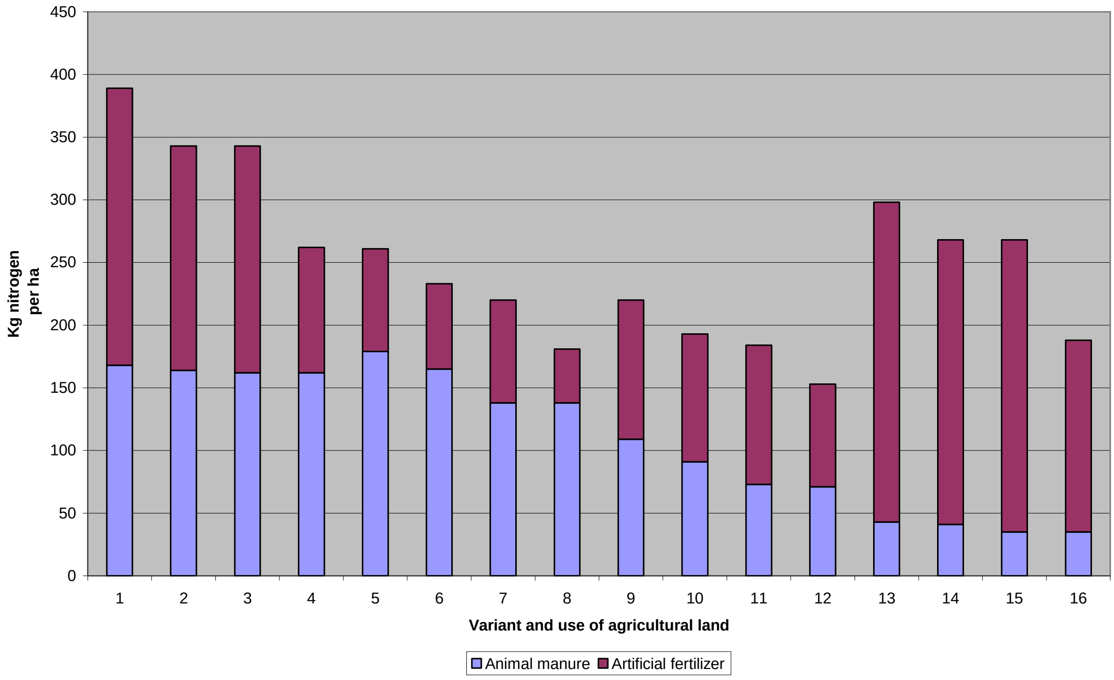



*Figure 7.6: Maximum application of nitrogen (kg per ha) per use of agricultural land (column 1-4 grassland; kolom 5 – 8 green maize; kolom 9 – 12 arable land and horticulture; column 13- 16 hobby farms) within the nitrogen application norms. The variants in the order as displayed 2006, 2009, 2015v1 en 2015v2.*

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., 2007). 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).

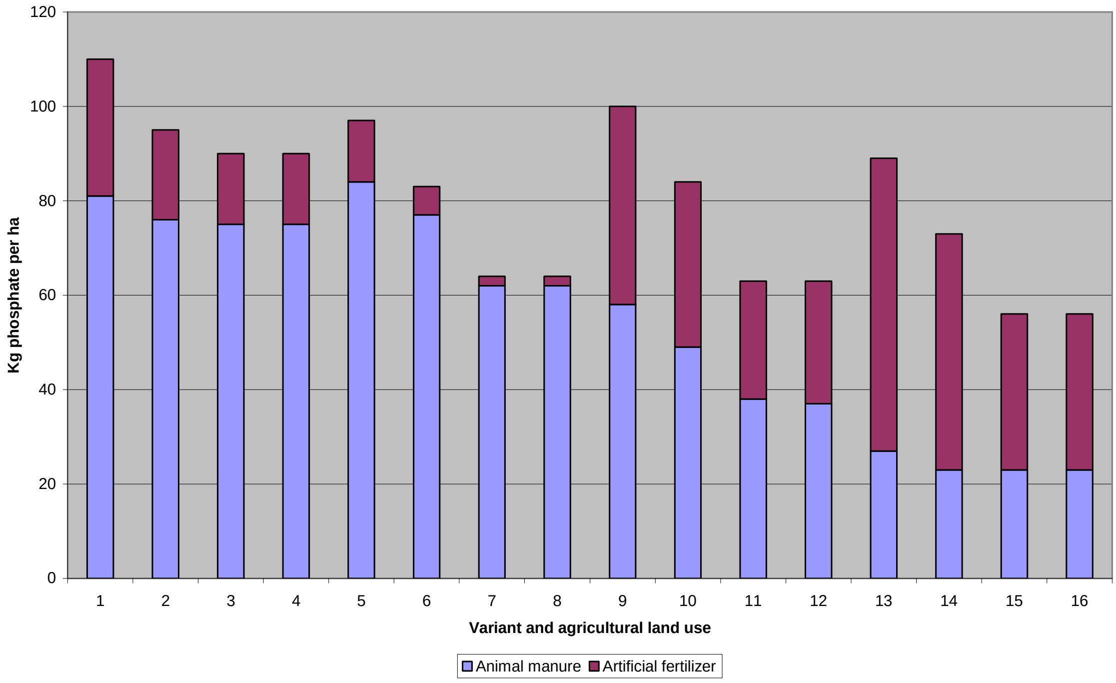



*Figure 7.7: Maximum application of phosphate (kg per ha) per use of agricultural land (column 1-4 grassland; kolom 5 – 8 green maize; kolom 9 – 12 arable land and horticulture; column 13- 16 hobby farms) within the nitrogen application norms. The variants in the order as displayed 2006, 2009, 2015v1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

The results for phosphate show a similar pattern. 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., 2007). 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.

## 7.4 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 7.3.4.

### 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, 1997 and Helming, 2003). 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 MAM 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.

### 7.4.1 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.
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 7.8.

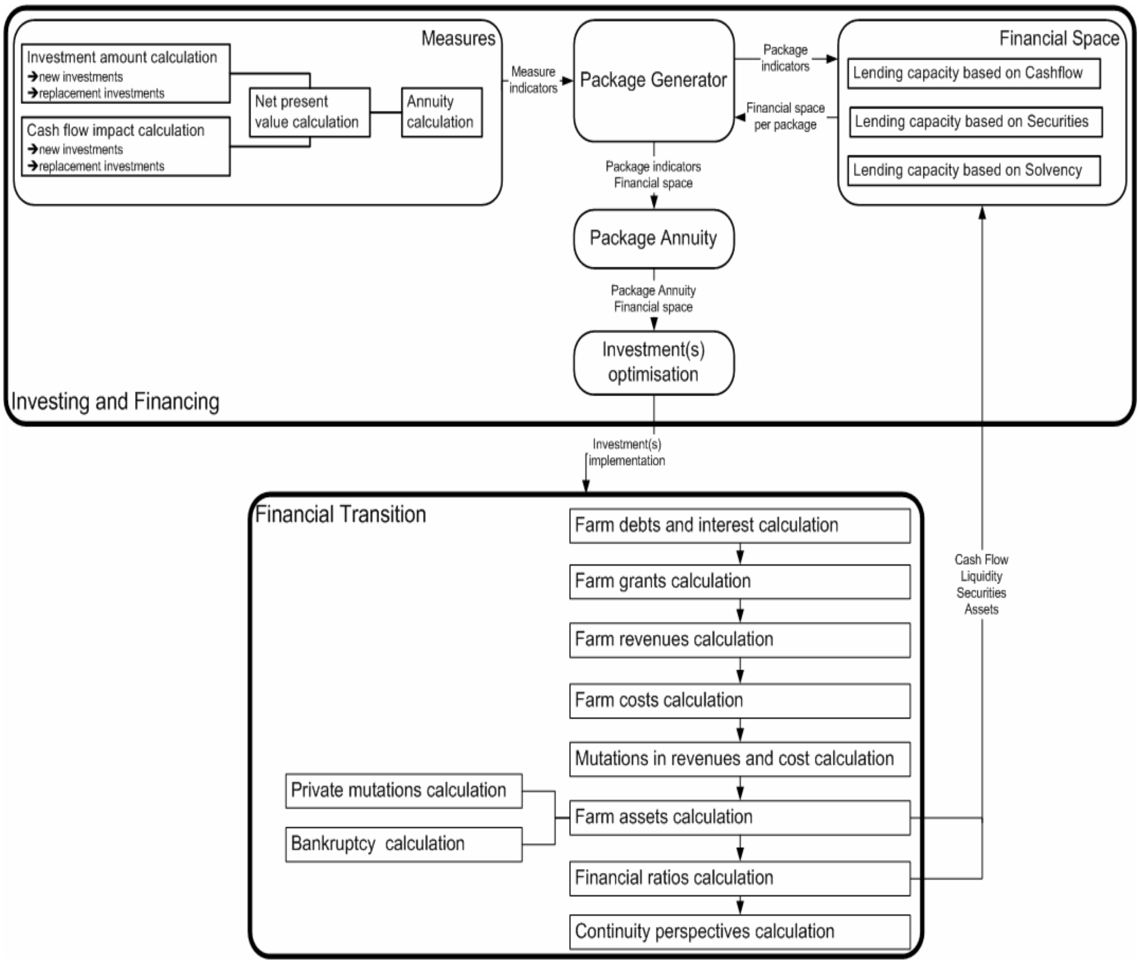



*Figure 7.8: overview of the financial simulation model (van Bommel and van der Veen, 2006)*

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 (see Brooke, 1998; McCarl, 2006). ). 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.

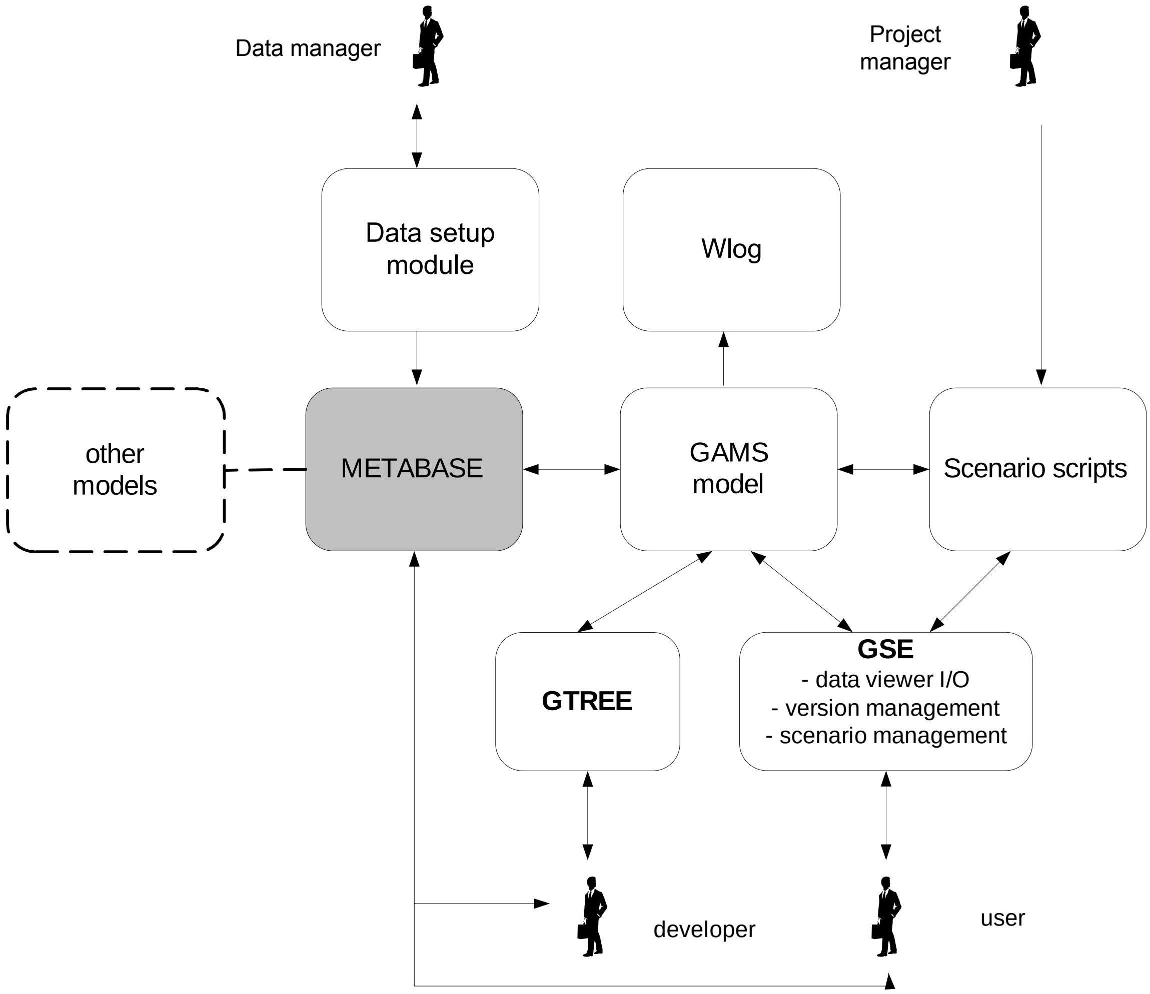



*Figure 8.1 Tools for the development and use of MAMBO*

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 () for converting text files into GDX files.

**GSE**

GSE was developed to run the model, and to present the results (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.

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.

### 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.

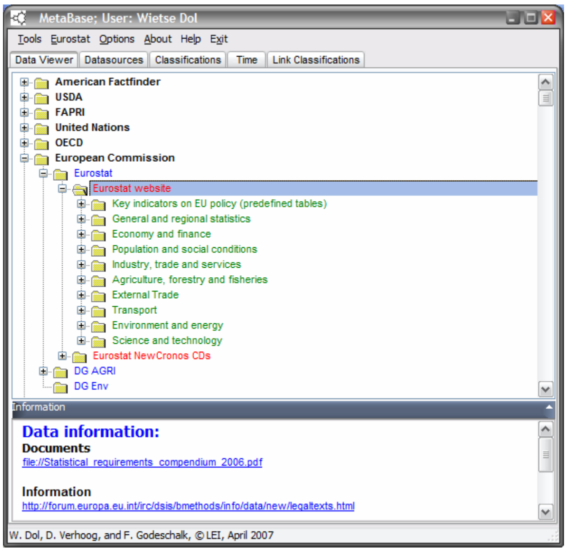


*Figure 8.2 Interface of metabase*

**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.

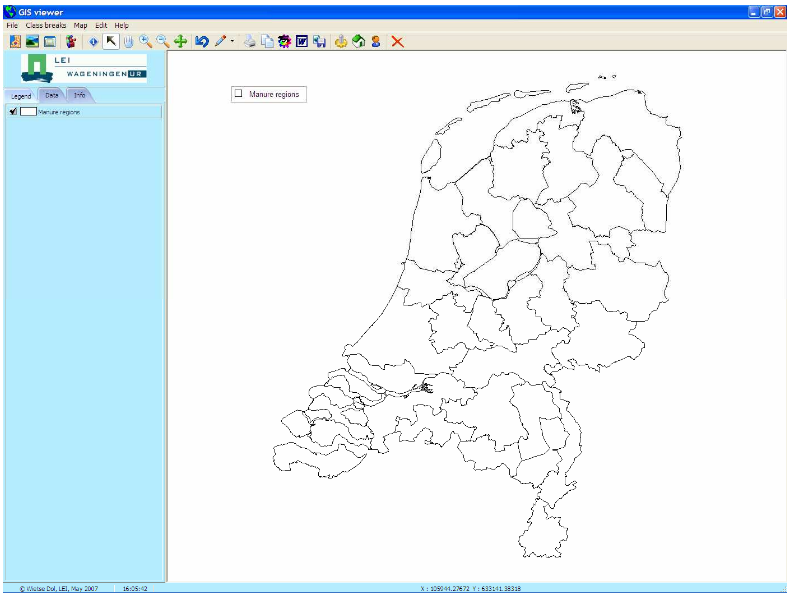



*Figure 8.3 GIS viewer with layout of 31 manure regions in the Netherlands*

## 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.

## 8.4 MAMBO output test procedure

To assure the quality of the output, working procedures and evaluation points have been defined. 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.

**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 can not 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 can not 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.

**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 paragraphs the evaluation points are discussed. This paragraph 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.

### Mineral production

Table 8.5.1 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 8.5.1 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 8.5.2 presents the nitrogen and phosphate production per manure category. The overall difference is .2%. For grazing beef cattle there is a difference of almost 2 percent. This difference will be further analyzed in the future.

*Table 8.5.2 Mineral production and difference in mineral production between MAM and MAMBO per manure category.*

| | Nitrogen | | | Phosphate | | |
|---|---|---|---|---|---|---|
| Manure category | 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% |

**Stable emission**

Table 8.5.3 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 8.5.3 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 |
|---|---|---|---|
| Sall. Twente e.o. | 4446 | 4459 | 99,7% |
| Peel land van Cuyk | 5024 | 5019 | 100,1% |
| Achterhoek | 3695 | 3710 | 99,6% |
| Maask Meijerij | 4104 | 4098 | 100,1% |
| Westnoord 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. Veenk. | 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% |

**Storage emission**

Table 8.5.4 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 8.5.4 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 |
|---|---|---|---|
| Sall. Twente e.o. | 261 | 262 | 99,4% |
| Peel land van Cuyk | 350 | 350 | 99,9% |
| Achterhoek | 219 | 220 | 99,4% |
| Maask Meijerij | 261 | 262 | 99,8% |
| Westnoord 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. Veenk. | 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, 2008). 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):

1. 15 % less broilers;
2. 7% less laying hens;
3. 8% less beef and;
4. 100% more sheep, horses and ponys.

### 8.6.2 Excretion of nitrogen and phosphate

Different studies (Tanmminga et al, 2004 and Jongbloed at al, 2005) describe uncertainties in the excretion of nitrogen an phosphate of animals. Table 8.61 given a summary of the uncertainties.

*Table 8.6.1 Uncertainty borders of N- en P2O5 excretion per animal catagorie (Bron: milkcows, Tamminga et al, 2004; pigs and poultry, Jongbloed et al, 2005).*

| Diercategorie | Index uncertainty borders nitrogen | | Index Uncertainty borders phosphate | |
|---|---|---|---|---|
| | Upperbound | lowerbound | upperbound | lowerbound |
| 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 1.500 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 1.500 farm 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 at 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, 2007 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 8.6.2.

*Table 8.6.2 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 8.6.3.

*Table 8.6.3 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 8.6.4.

*Table 8.6.4 Nitrogen and phosphate production by the variants for the uncertainty analyses in The Netherlands in 2006 in million kg*

| | 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 1.500 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 8.6.5).

*Table 8.6.5 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 8.6.6).

*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 8.6.6 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*

| | 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.

# 9 Concluding remarks

The release of MAMBO is the end of 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.

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## References


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

Bouma, F., W. Dol, H. Luesink, D. Oudendag, T. Verwaart and 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, Cor van, 2007. Dierlijke mest en mineralen 2005. Internetpublicatie: http://www.cbs.nl/NR/rdonlyres/EF9A77E2-C0DB-43F3-B412-FC0216668E49/0/2005dierlijkemestenmineralenart.pdf

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

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

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

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

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

GAMS Development Corporation. 2006. *GAMS GDX facilities and tools*. Washington D.C.: GAMS Development Corp. URL: http://www.gams.com/contrib/GDXUtils.pdf

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.

Hoogeveen, M.W., H.H. Luesink, L.J. Mokveld en J.H. Wisman, 2006. Uitgangspunten en berekeningen voor de milieubalans 2007. LEI, Den Haag, in press

Hoogeveen, M.W., P.W. Blokland, H.H. Luesink, A. Netjes en H. Prins, 2007a. Instrumentarium monitoring mestmarkt en enkele analyses. LEI, Den Haag, Rapport in voorbereiding

Hoogeveen, M.W., M.J.C. de Bode, J.N. Bosma, P.W.G. Groot Koerkamp, H.A.C. Verkerk en O. Oenema, 2007b. Synthese monitoring mestmarkt 2006, LEI, Den Haag en CDM, Wageningen, Rapport in voorbereiding

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

Hordijk, L., 2004. Mest- en ammoniak model, audit in het kader van het project 'Kwaliteitsborging modellen en databestanden'. Report WUR, Wageningen

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

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. URL: http://www.gams.com/~erwin/interface/wlog.pdf

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

Luesink, H.H., A.N. Bosma, P.W. Blokland, L.J. Mokveld en M.G. Hoogeveen, 2008 Monitoring mestmarkt 2006. LEI, Den Haag , in press

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

Luesink, H.H., C.H.G. Daatselaar, G.J. Doornewaard, H. Prins en D.W. de Hoop, 2004a. 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., 2004. Ammoniak uit de landbouw verder teruggelopen. Agrimonitor 10 (3): 8

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, 2007a Monitoring mestmarkt2006 Achtergronddocumentatie. LEI, Den Haag, To be published.

Luesink, H.H., P.W. Blokland en L.J. Mokveld, 2007b Situatie mestmarkt 2009-2015. LEI, Den Haag, To be published.

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

McCarl, B.A., A. Meeraus, P. van der Eijk, M. Bussieck, S. Dirkse, and P. Steacy. 2006. GAMS User Guide: 2006 Version 22.2. Texas A&M University with GAMS Development Corp. For latest version: URL: http://www.gams.com/dd/docs/bigdocs/gams2002/mccarlgamsuserguide.pdf

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

MNP, 2006a Emissieregistratie. www.emissieregistratie.nl

MNP, 2006b Milieubalans 2006. MNP, Bilthoven

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

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

RIVM/CBS, 2004. Milieucompendium 2004. RIVM/CBS, Bilthoven en voorburg

Robbins, A.D. 2004. *GAWK: Effective AWK Programming: A User's Guide for GNU Awk Edition 3.* Boston, MA: Free Software Foundation. URL: http://www.gnu.org/software/gawk/manual/Gawk.pdf

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

Smits, M.C.J., J.A. Van Jaarsveld, L.J. Mokveld, O. Vellinga, A.P. Stolk, K.W. Van der Hoek and W.A.J. Van derPul, 2005. Het 'VELD'-project: een gedetailleerde inventarisatie van de ammoniak-emissies en –concentraties in een agrarisch gebied. Report A&F, 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. Oenenma en G.J. Monteny. Actualisering van geschatte N en P excreties door rundvee, 2004.

Wageningen, WUR, Reeks Milieu en Landelijkgebied 25

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 Nutrientenbelasting 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 (in voorbereiding).

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.

# Appendix 1 Example animal categories

Animal categories for 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** | **Base run** | **Comparison run** | **Scenario specific output** | **Test discipline** |
|---|---|---|---|---|
| Country_variant_scenario_datayear | | | | |
| | | | | |
| **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_ | No | NLD_P30883_2005 | Yes | Basic |

| | | | | |
|---|---|---|---|---|
| MinFertApplMin/Plus_2005 | | | | 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 |
| 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<br>Expert judgement |