# Ex-ante evaluation of tightening environmental policy: the case of mineral use in Dutch agriculture

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*Abstract*— **Non-point source pollution is notoriously difficult to asses. A relevant example is mineral emissions in the Netherlands. Since the mid 1980s the Dutch government has sought to reduce emissions through a wide variety of measures, the effect of which in turn is monitored using modeling techniques.**

**This paper presents the current generation of mineral emission models from agriculture based on micro-simulation of farms in combination with a spatial equilibrium model for the dispersion of manure from excess regions with high livestock intensities within the country to areas with low livestock intensities. The micro-simulation approach retains the richness in the heterogeneity of farm household decision making that are the core cause of the difficulty of assessing non-point source pollution, while using the best available data to track corresponding pollution. Using scenario analysis we are able to assess the possible effects of further tightening of agro-environmental policy.**

*Keywords*— **micro-simulation, spatial-quilibrium model, non-point source pollution**

## I. INTRODUCTION

Non-point source pollution is notoriously difficult to asses, precisely because it is diffuse, usually with many sources that are often difficult to monitor. At best aggregate figures can be provided based selected measurements which tends to be unsatisfactory for policy assessment purposes where the precise effects of policy interventions is desired. Relevant examples are ammonia emissions and nitrate and phosphate leaching from agriculture to ground and surface water in the Netherlands.

One of the ways of addressing the issue of non-point source pollution is to use models to estimate emissions of pollutants into the environment. In this paper we discuss combined micro-simulation models with a spatial equilibrium model to deal with the fore mentioned pollution issues from agriculture. We believe that micro-simulation is a powerful tool to address the issue of non-point source pollution because it deals with the processes that cause the pollution. In this paper we present MAMBO a micro-simulation model of livestock and agriculture that looks at the mineral flows within the sector and the resulting emissions.

The structure of the paper is as follows. In the next section we discuss the issue of mineral emissions from agriculture. Next we present the model itself and its mathematical equations, after which we discuss the data that enters into the model. We then go on to discuss model results with respect to the effects of environmental policies. We wrap up our paper with a brief discussion of the results and model.

## II. EMISSIONS FROM LIVESTOCK AND AGRICULTURE

In the past decades point-source pollution to air and water have been lowered dramatically. Effective legislation with both command and control measures and economic instruments have reduced emissions of many pollutants to a bare minimum.

Identification and quantification of non-point source pollutants have proven difficult and have thus limited the implementation of appropriate and effective solutions. Currently, most strategies that address non-point source pollution are driven by dissociated economic, political and ecological interests that are difficult to reconcile. As a result non-point source pollution is typically not well regulated.

Atmospheric ammonia in the Netherlands is amongst the highest in the world, due to a large extent to the high population density of farm animals [1]. The high animal density also threatens water quality through the leaching of nitrate and more importantly phosphate to groundwater [2]. The role of livestock and agriculture in emissions can be represented graphically in Figure 1. The flags represent points within the system where ammonia emissions occur. At flag number 6 we also find the emission of nitrate and phosphate to ground water.

The ability to monitor the effects of policies that influence the processes in this system allow legislators to construct meaningful policy frameworks that address both ecological and economic indicators. In the Netherlands we have a long history of addressing the emissions from agriculture and livestock, both analytically and in terms of legislation.

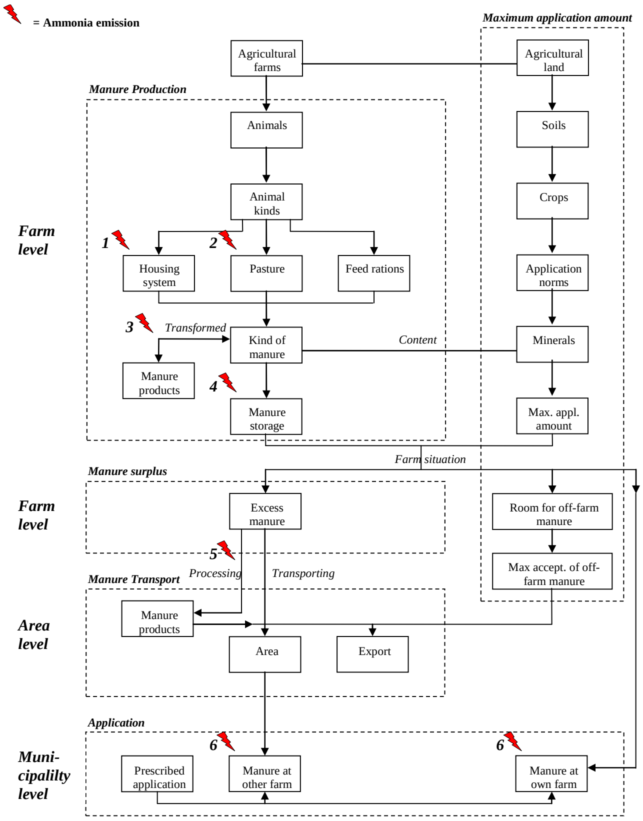

Fig. 1 The manure and mineral emission model structure

## III. MAMBO MODEL

Following the structure of mineral flows in agriculture highlighted in figure 1 we develop a model MAMBO is a suite of modules written in GAMS (General algebraic modelling system [3] 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. It loosely follows the tradition of micro-simulation modelling [4][5].

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 in the grazing season. 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, namely firms identifier, establishment number and municipality code). 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 (subscript a) per department (subscript d) per farm establishment and per ration type (subscript $\rho$).

$$B^{manure}_{\rho da} = N^{animals}_{da} * \rho_{\rho a} * v_{\rho a} * \tau_{\rho da} \qquad (1)$$

Within MAMBO, manure categories (subscript f) 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.

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

Mineral (subscript m) 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.

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

The mineral content of manure warrants a little extra explanation. In MAMBO certain standardized procedures are used. This is the basis of the multiple mineral accounting framework used in the modelling procedures. 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 emission factors (subscript φ: 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 4 and 5. The emission is expressed as kg mineral emitted per animal category per department (hence per mineral category) per farm and emission kind (one of them is ammonia).

$$E^{stable}_{\varphi m d^s a f} = M^{manure,scientific}_{m d^s a f} * \varepsilon^{stable}_{\varphi m d^s f} \qquad \text{(4, flag 1 in Figure 1)}$$

$$E^{pasture}_{\varphi m d^p a f} = M^{manure,scientific}_{m d^p a f} * \varepsilon^{pasture}_{\varphi m d^p f} \qquad \text{(5, flag 2 in Figure 1)}$$

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.

$$M^{manure,scientific,after\,emissions}_{mdaf} = M^{manure,scientific}_{mdaf} - \sum_{\varphi} \left( E^{pasture}_{\varphi mdaf} + E^{stable}_{\varphi mdaf} \right) \qquad (6)$$

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 ($s_{do}$, where subscript o denotes storage types) is used to distinguish what storage systems are applicable on average for each firm.

$$E^{storage}_{mdfo} = s_{do} * \varepsilon^{storage}_{\varphi do} * \sum_{a} M^{manure,scientific,after\,emissions}_{mdaf} \qquad \text{(7, flag 4 in Figure 1)}$$

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 (A) 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 ($l^m$) that is defined for different crops (subscript c) 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 8.

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 (e). 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 ($\gamma^{\text{Min effect coef}}$), which is also regionally specific. This is summarized in equation 9.

$$M_m^{Max\,allowable,crops} \leq \sum_{sc} \left( \begin{array}{l} \sum_{\delta} \left( D_{\delta}^{derogation} * l_{m\delta c}^{m} \right) * \\ A_{sc}^{crops} * \left( 1 + l^{allowance} \right) \end{array} \right) \quad (8)$$

$$M_{mf}^{Max\,allowable,crops} \leq$$

$$\sum_{sc} \left( \begin{array}{l} \sum_{\delta\sigma^{own}} \left( D_{\delta}^{derogation} * \left[ \frac{\left( l_{m\delta sc|r}^{f} - e_{mc}^{Min\,application} \right)}{\gamma_{m\sigma^{own}scf|n}^{Min\,effect\,coef}} \right] \right) \\ * A_{sc}^{crops} * \left( 1 + l^{allowance} \right) \end{array} \right) \quad (9)$$

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 10)[1].

$$M_m^{Actual,crops} = \sum_{ad^s f} \left( M_{md^s af}^{manure,\,fixed} \right) \quad (10)$$

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. [2]

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 subject to the above constraints.

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. We derive an equation to capture the constraints related to the fertilization norms. As example we present the one for legal fertilizer standards:

$$\sum_{\delta\sigma^{own}} \left( D_{\delta}^{derogation} * \left[ \frac{\left( l_{m\delta sc|r}^{f} - e_{mc}^{Min\,application} \right)}{\gamma_{m\sigma^{own}scf|n}^{Min\,effect\,coef}} \right] \right) *$$

$$A_{scdf}^{crops\,with\,own\,manure} * \left( 1 + l^{allowance} \right) \geq \quad (11)$$

$$B_{dfsc}^{own\,manure,applied\,own\,crops} * \left[ \frac{\sum_{a} M_{mdaf}^{manure,\,fixed}}{\sum_{a} B_{daf}^{manure}} \right]$$

We also define a manure volume balance and a cropped area balance .

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

$$B_{daf}^{manure,surplus} = 0 \quad \text{and} \quad A_{sc}^{crops} - \sum_{df} \left( A_{scdf}^{crops\,with\,own\,manure} \right) \neq 0$$

The objective function becomes:

$$\max A_{scdf}^{crops\,with\,own\,manure} \quad (12)$$

for the crop with first preference for manure, abiding by non-negativity constraints and rules regarding allowed crop fertilizer combinations. This implies that there are no degrees of freedom left and optimization is complete.

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

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[1] 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

[2] 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 farm.

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.

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. A second important difference is that the scale at which we calculate the spatial equilibrium is different. Now the scale is a regional area. These regional areas are the manure regions (subscripts r and R) defined at the national level and used in spatial disaggregation of policy instruments. 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.

$$B_{df|r}^{manure,surplus} + B_{df|r,t-1}^{Storage} = \sum_{R} B_{df|r\rightarrow R}^{manure,transported} + \sum_{\omega} B_{df\omega|r}^{manure,\,processed} + B_{df|r}^{manure,Exported} + B_{df|r}^{Storage} \qquad (13)$$

where the total amount of exported manure and processed manure are limited by demand constraints that are given exogenously. The processed manure has its own dynamics. For exposition sake we omit these complexities in this presentation.

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. The acceptation degree factor depends on perceived risk of using off-farm manure and estimated empirically.

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

$$Q_{df|r\rightarrow R}^{\substack{manure\ product,\\ transported}} * \left[ \frac{M_{mdf|r}^{manure\ product,scientific}}{\left( \begin{array}{l} Q_{df|r}^{manure\ product,Exported} + \\ Q_{df|r}^{manure\ product,Dumped} + \\ Q_{df|r\rightarrow R}^{manure\ product,Transported} \end{array} \right)} \right] + B_{df|r\rightarrow R}^{manure,transported} * \left[ \frac{\sum_{a} M_{mdaf|r}^{manure,scientific}}{\sum_{a} B_{daf|r}^{manure}} \right] \qquad (14)$$

The left-hand side of equation 14 signifies potential demand. The right-hand side is supply.

The objective function becomes:

$$\min C^{AggregateCost} - \Pi^{Aggregate\ revenues} \qquad (15)$$

Where CAggregate Cost are the aggregate costs, and ΠAggregate revenue are aggregate revenues from manure distribution:

$$C^{Aggregate\,Costs} =$$

$$\sum_{df}\left(\begin{matrix}
\sum_{r\to R|r=R}\left(\sum_{\mu\in M\mu f}\left(\begin{pmatrix} c_{\mu}^{fixed,in\,r}+c_{\mu}^{storage,in\,r}\\ +\sum_{\sigma^{offfarm}} c^{application}_{\sigma^{offfarm}f}\end{pmatrix}*\begin{pmatrix}B^{manure,transported}_{df|r\to R}+\\ Q^{manure\,product,transported}_{df|r\to R}\end{pmatrix}\right)\right)+\\
\sum_{r\to R|r\neq R}\left(\sum_{\mu\in M\mu f}\left(\begin{pmatrix} c_{\mu}^{transport}*d_{r\to R}+\\ c_{\mu}^{fixed,out\,r}+\\ c_{\mu}^{storage,out\,r}+\\ \sum_{\sigma^{offfarm}} c^{application}_{\sigma^{offfarm}f}\end{pmatrix}*\begin{pmatrix}B^{manure,transported}_{df|r\to R}+\\ Q^{manure\,product,transported}_{df|r\to R}\end{pmatrix}\right)\right)+\\
\sum_{\omega|r}\left(\begin{matrix}\left(\begin{matrix}\sum_{\mu\in M\mu f}\begin{pmatrix}c_{\mu}^{storage,\,processed\,manure}+\\ c_{\mu}^{fixed,\,Sector}\end{pmatrix}+\\ c^{process}_{\omega f}\end{matrix}\right)*\\ B^{manure,\,processed}_{df\omega|r}\end{matrix}\right)\\
\sum_{r}\left(\sum_{\mu\in M\mu f}\begin{pmatrix}c_{\mu}^{fixed,\,Export}*\\ \begin{pmatrix}B^{manure,\,Exported}_{df|r}+\\ Q^{manure\,product,\,Exported}_{df|r}\end{pmatrix}\end{pmatrix}\right)+\\
\sum_{sc}\left(c^{risk\,penalty}_{scdf}*I^{crops\,with\,offfarm\,manure}_{scdf|R}\right)
\end{matrix}\right) \tag{16}$$

and

$$\Pi^{Aggregate\,revenues} =$$

$$\sum_{r\to R,r=R}\left(\pi^{manure\,revenue}_{fR}\begin{bmatrix}B^{manure,transported}_{df|r\to R}\\ +Q^{manure\,product,transported}_{df|r\to R}\end{bmatrix}\right) \tag{17}$$

For surplus manure in a specific region the following possibilities exist: supply within the region; supply to other regions; export.

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 equation 8-12) and placement of off-farm manure and manure products (from equation 13-17).

$$A^{crops,not\ fertilized}_{\delta sc|m} = A^{crops}_{\delta sc|m}-\sum_{df}\begin{pmatrix}A^{crops\,with\,own\,manure}_{scdf|m}+\\ A^{crops\,with\,offfarm\,manure}_{scdf|m}+\\ A^{crops\,with\,manure\,products}_{scdf|m}\end{pmatrix} \tag{18}$$

$$\sum_{\delta\sigma^{offfarm}}\left(\left[\frac{\left(l^{f}_{m\delta sc|R}\right)}{\gamma^{Min\,effect\,coef}_{m\sigma^{offfarm}scf|m}}\right]\right)*\left(\left[A^{crops,not\ fertilized}_{\delta sc|m}\right]\right)* \left(1+l^{allowance}\right)\geq I^{artificial\ \ fertilizer}_{\delta fsc|m}*\mu_{mf} \tag{19}$$

with

$$e^{Min\,application}_{mc}\leq\frac{\sum_{f\in m}\left(I^{artificial\ \ fertilizer}_{\delta fsc|m}*\mu_{mf}\right)}{\sum_{f\in m}\left(A^{artificial\ \ fertilizer}_{\delta fsc|m}\right)} \tag{20}$$

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

$$E_{\varphi mscf|s}^{Organic\,application} = \left( \sum_{\kappa\delta\sigma\eta\mu} \begin{pmatrix} M_{m\delta\sigma fsc}^{\substack{Organic\,Minerals \\ applied\,to\,crops}} * \\ \eta_{\eta\mu sc}^{application\,utilization} * \\ \varepsilon_{\varphi m\kappa\eta\mu}^{application} * \\ \varphi_{m\kappa f}^{Mineral\ fraction} \end{pmatrix} \right) * \gamma_{mcf|s}^{Mineral\,effect} * \varphi_{sc|s}^{season\,application} \quad \text{(21, flag 6 in Figure 1)}$$

$$\mu \in \Phi_{\mu f},\ f \in \{ f^{m}, f^{mp} \}$$

For artificial (inorganic) fertilizers a different equation is used

$$E_{mscf^{a}|s}^{Inorganic\ application} = I_{\delta scf^{a}}^{Artificial\ fertilizer} * \mu_{mf^{a}} * \varepsilon_{mf^{a}}^{Artificial\ fertilizer} \quad \text{(22, flag 6 in Figure 1)}$$

## IV. DATA

Data is crucial in micro-simulation models because individual actors and their characteristics are taken into account. In this section we discuss the data that is used in the model, and their principal sources. Information on individual farms comes from the Agricultural Census with additional information from the Dutch farm accountancy data network (a sample of about 1500 agriculture and horticulture farms). Technical coefficients are determined by the WUM (state committee for determining consensus technical coefficients) estimates each year the manure excretion of animal categories that are relevant for the manure policy and the CBS determines the mineral content [6]. The agricultural mineral effect coefficient is a fraction per mineral, crop and fertilizer category, based on scientific research or expert judgment.

For legal standards the data is taken from legislation. Other data is obtained from The Regulatory Agency of the Ministry of Agriculture, Nature, and Fisheries (LNV-DR). For soil distribution we rely on Farm Plots Registration (BRP, LNV-DR) as a result of which each firm receives it's specific soil distribution. They also provide data on manure trade (exports, processing) based on transport registration forms of transport companies. For monitoring the manure market LNV-DR provides the registered transported manure and minerals. This information is first verified and aggregated by the Statistics Bureau CBS.

## V. RESULTS

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 2 displays the predictions of the production of phosphate for four different years. Figure 3 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).

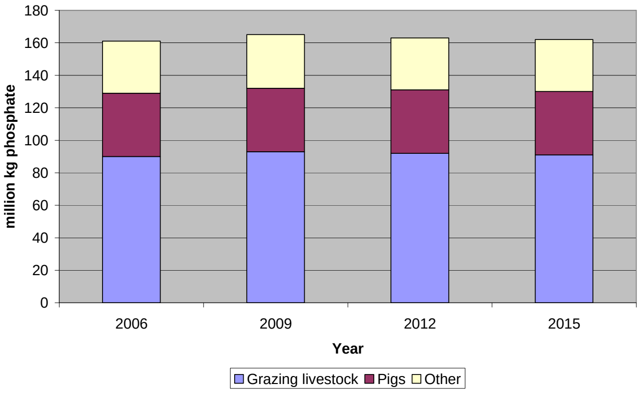

Fig. 2 Estimated production of phosphate in 4 different years

The estimated phosphate production for 2009 is slightly higher than for 2006 (see Figure 2). 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.

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 3). 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).

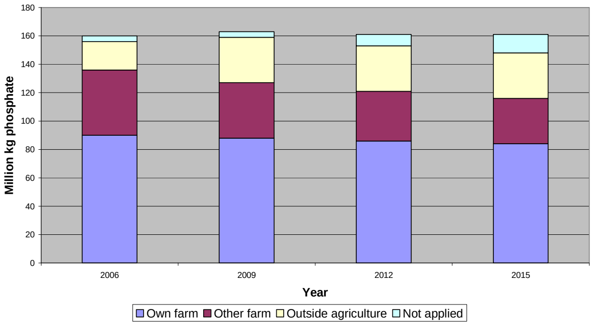

Fig. 3 Estimated application of phosphate (for the year 2006, 2009, 2012, 2015)

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. Figure 3 also displays 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).

## VI. DISCUSSION AND CONCLUSIONS

In the paper we presented MAMBO a combined micro-simulation model and a spatial equilibrium model for simulating relevant actors behaviour with regard to manure and artificial fertilizer in order to get a handle on emissions of pollutants (nitrate, phosphate and ammonia) from livestock and agricultural activities. The models were calibrated with empirical data from regulatory agencies. Validation of model components has been conducted on a number of occasions. The results from the modeling framework are robust and form the basic input into policy discussions in the Netherlands on non-point source pollution from agriculture. The results are being used to evaluate policies both ex-post to see the impact the policies have had on both emissions and on economic indicators related to the manure market.

We feel that micro-simulation for addressing policy issues related to non-point source pollution is the way forward. The modeling framework MAMBO we use is flexible enough to take into account changing policies while still capturing the behavior of economic actors. Our choice of model has been a combination of micro-simulation and a spatial equilibrium model for the manure market. Obviously there is still a lot of work that can be done to improve the performance of the model, especially where it concerns explorations of the future. This is primarily due to the fact that the current applications of the model concentrate on monitoring current levels of pollution where a lot of variables are known (prices, investment decisions, production structure). By linking the model to investment modules we will be able to simulate possible changes in the structure of agriculture.

At present it suffices to say that MAMBO is able to deal with the complex issues of non-point source pollution in a way that offers scope for the future.

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