Wim de Vries, Hans Kros, Gerard Velthof

Alterra, Wageningen UR
Visiting Address: Droevendaalsesteeg 3, Building 101
P.O. box 47, 6700 AA Wageningen, The Netherlands
Tel +31-317-474353
e-mail: wim.devries@wur.nl

Integrated evaluation of agricultural management on environmental quality with a decision support system

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ABSTRACT
To gain insight in the environmental impacts of excessive manure and fertilizer applications, an integrated regional scale model system INITIATOR2 was developed predicting: (i) emissions of ammonia, greenhouse gases (CO_2, CH_4 and N_2O), odor and fine particles from animal housing systems and terrestrial ecosystems (including peat lands) and (ii) accumulation and leaching and runoff of carbon, nutrients (nitrogen, phosphate and base cations) and metals from agricultural soils to ground water and surface water. This paper provides an overview of INITIATOR2 and a demonstration how the model was used to evaluate mitigation measures, in terms of good agricultural practices and technical measures such as changes in animal housing, in Dutch agriculture. The measures focused on the reduction of emissions of nitrogen compounds to air, ground water and surface water. The measures, which have a fast and large effect on N emissions also lead to a significant reduction in the emission of methane and in the soil accumulation of phosphate and metals, but the impact on the leaching and runoff of the latter compounds is small at least within the investigated 30 year period.

KEY WORDS: agriculture, decision support system, nitrogen, greenhouse gases, manure, mitigation measures.

INTRODUCTION

The Netherlands is one of the countries with the highest reactive nitrogen emissions density in the world, where reactive nitrogen stands for all forms of oxidized and reduced nitrogen except for N_2. The animal manure production in the Netherlands is approximately five times the average European value per unit of agricultural area (OECD, 2001). These enhanced levels of reactive nitrogen in the environment (in air, soil, ground water and surface water) lead to a cascade of effects (Cowling et al., 1998). Observed effects in the Netherlands, for which different targets are defined, include (Erisman et al., 2001): (i) decreased species diversity and acidification of non-agricultural soils (focus on NH_3 and NO_x emission targets), (ii) impacts on human health and plants due to ozone for which NO_x is a precursor (focus on NO_x emission targets), (iii) global warming (focus on N_2O emission targets), (iv) pollution of ground water and drinking water due to nitrate leaching (focus on N application and N loss targets) and (v) eutrophication of surface waters, including excess algal growth and a decrease in natural diversity (focus on N application and N loss targets).

Apart from nitrous oxide (N_2O) emissions, excessive manure input also causes emissions of other greenhouse gases, mainly methane (CH_4), and accumulation and/or elevated leaching and runoff of various compounds, including carbon, nitrogen, phosphate, base cations and metals from agricultural soils to ground water and surface water. Approximately half of the N_2O and CH_4 emissions in the Netherlands stems from agriculture (Olivier et al., 2002) and the net contribution to the warming potential is of even greater importance. Changes in soil carbon are relevant in view of soil fertility and the role of the soil as a sink or source of CO_2. Together with N, P is generally considered to be the key element controlling the ecological quality of fresh waters. The potential impacts of P loads by manure and fertilizer on agricultural soils on the eutrophication of surface water is thus a major concern in the Netherlands (Van der Zee, 1988; Schoumans and Groenendijk, 2000). Recently, the contribution of heavy metals in agricultural soils to the leaching and runoff to ground water and surface water has also become of concern as it has large impacts on the water quality (Römkens et al., 2003).

At present, different targets are defined in the Netherlands, directed towards atmospheric emissions or concentrations of elements in ground- and surface water. National ammonia emission targets in Gg $NH_3.yr^{-1}$ are 100 for the year 2010, 50 for the year 2020 and 30 for the year 2030. Considering an estimated annual ammonia emission in the Netherlands in 1995 of 175 Gg NH_3 (RIVM/CBS, 1999),this implies a succeeding decrease in ammonia emissions of approximately 45%, 70% and 80% compared to this target year. Reductions in are also specifically aiming at decreasing N inputs to land. The Dutch target for NO_x emissions, that mainly stem from traffic and industry and hardly from agriculture, is 238 Gg $NO_x.yr^{-1}$ for all sources. The present emission is approximately 370 Gg $NO_x.yr^{-1}$. The targets for NH_3 and NO_x emissions both aim to avoid adverse impacts of elevated N inputs to terrestrial ecosystems, specifically in terms of a decrease in biodiversity. Finally, the total emission target for greenhouse gases, including N_2O, is a 6% decrease compared to 1990, whereas the ultimate target is background emission. The aim related to N leaching and runoff is such that the NO_3 concentration in upper groundwater stays below the EU quality criterion of 50 $mg.l^{-1}$ (Anonymous, 1991) and the N concentration in stagnant surface waters below a concentration of 2.2 $mg.l^{-1}$. The P concentration in stagnant surface waters should stay below a concentration of 0.15 $mg.l^{-1}$ and concentrations of the heavy metals Pb, Cd and Cu in surface water should stay below 11, 0.19, 1.5 $ug.l^{-1}$, respectively. For Zn it varies between 8.8-42.8 $ug.l^{-1}$, depending on the Zn background concentration.

Measures to control problems related to animal manure inputs in the Netherlands were up to recently directed towards different environmental themes including ammonia emission, emission of greenhouse gases, nitrate leaching to ground water and runoff of nitrogen and phosphate to surface water. To gain insight in all environmental impacts of excessive manure and fertilizer application simultaneously, an integrated model INITIATOR2 was developed (De Vries et al., 2005). The policy aim of INITIATOR2 (Integrated Nutrient ImpacT Assessment Tool On a Regional scale) is to present information on the effectiveness of policies aimed at the simultaneous reduction of all relevant element fluxes (nutrient and contaminants) to atmosphere, ground water and surface water. INITIATOR2 is unique by its simultaneous inclusion of gaseous emissions, soil accumulation, leaching and runoff of so many compounds. There are other studies in which the impact of measures on various gaseous emissions is investigated (De Vries et al., 2005) but those studies do not include a soil and water component. This paper provides an overview of the integrated regional scale model INITIATOR2 and a demonstration how the model can be used for the evaluation of mitigation measures in terms of emissions of NH_3, N_2O and CH_4 and to the accumulation and leaching/runoff of N, P and Zn.

MODELLING APPROACH AND MODEL APPLICATION

Processes considered in INITIATOR2

INITIATOR2 is an extension of the model INITIATOR (Integrated NITrogen Impact Assessment Tool On a Regional scale) that was developed to: (i) gain insight in the fate of all major nitrogen flows in the Netherlands (De Vries et al., 2003), (ii) calculate 'regional specific nitrogen ceilings' (maximum amounts of reactive nitrogen that do not lead to exceedance of critical limits or targets) (De Vries et al., 2001b) and (iii) assess the impacts of improved agricultural practices and technical measures such as changes in animal housing on nitrogen fluxes in the Netherlands (De Vries et al., 2001a). INITIATOR is a simple N balance model based on empirical linear relationships between the different N fluxes. We have chosen a simple approach to maintain transparency and to be able to apply the model with available data. The processes and fluxes treated in INITIATOR2 (N now stands for nutrients) are (De Vries et al., 2005):

- Emissions of fine particles and odor from housing and manure storage systems
- Emissions of NH_3, NO_x and N_2O from housing and manure storage systems, soils and surface waters (not NH_3; focus of INITIATOR)
- Emissions of the greenhouse gases CO_2 and CH_4 from housing and manure storage systems (not CO_2) and terrestrial systems (with a focus on peat soils).
- Atmospheric dispersion of NH_3 and NO_x followed by N deposition
- Plant uptake, soil accumulation/release (mineralization/immobilization and adsorption/desorption), leaching and runoff of nitrate and ammonium (focus of INITIATOR), phosphate, base cations (Ca, Mg, K) and heavy metals (Pb, Cd, Cu and Zn) to ground water and surface water.

General modeling approach

A flow chart of the considered element inputs and element transformation processes in the model INITIATOR2 is given in Figure 1. The flow chart is limited to the agricultural part of the model. INITIATOR2 can also be applied to non-agricultural soils where the input of N and metals is limited to atmospheric deposition.

Figure 1

A so-called GIAB database contains animal numbers for each farm in the Netherlands, based on results from daily questionnaires from the Dutch Central Bureau on Statistics (CBS). In this study, use was made of the data for the year 2000 as a reference year for the calculations (Anonymous, 2001). The emissions of NH_3, NO_x, N_2O, CH_4, fine particles and odor from housing and manure storage systems are described by a multiplication of the animal numbers with either an N excretion factor and emission fractions (NH_3, NO_x, N_2O) or as animal specific emission factors (CH_4, fine particles and odor) for different animal categories, depending on the type of emission (a maximum of 65 categories in case of N excretion and NH_3 emission). The excretion of carbon, nutrients (nitrogen, phosphate and base cations) and metals in manure is calculated by a multiplication of the animal numbers for each farm with the excretion per animal. This excretion, corrected for volatilization in case of N, is input for a simple manure and fertilizer application module that predicts the inputs of C, N, P, base cations and metals to the soil, both by manure and by the related N and P fertilizer use.

The INITIATOR2 soil model calculates the soil emissions of NH_3, NO_x, N_2O, CH_4 and CO_2 from terrestrial systems and the accumulation, leaching and runoff of carbon, nutrients (nitrogen, phosphate and base cations) and metals to ground water and surface water as described in detail below. The NH_3 emissions in the field and those from housing systems form the input of a simple atmospheric transport model (a transfer matrix based on results of the atmospheric transport model OPS (Van Jaarsveld, 1995) to assess the N deposition on agricultural and non-agricultural systems. Measures can affect animal numbers (CBS/ GIAB database), excretion factors or emission fractions or parameters in INITIATOR2 influencing the fate of elements in soil, ground water and surface water (see Figure 1).

Schematization of the study area

In this study, INITIATOR2 was applied to all agricultural soils in the Netherlands. Geo-referenced data for the N input via animal manure and fertilizers were based on data statistics at farm level for the year 2000, using the CBS/ GIAB data combined with a manure transport model. Applied animal manure was divided in cattle, pig and poultry manure and in dung and urine deposited on grassland by grazing animals, since this has an influence on the ammonia emissions from the soil. Nitrogen and metal deposition data for the year 2000 were based on results of the atmospheric transport models OPS at a 1 km x 1 km grid scale for N and a 10 km x 10 km grid scale for Zn (Bleeker, 2004). P deposition was neglected. N fixation was estimated as a function of land use (De Vries et al., 2003).

For agriculture, a total number of 4647 plots were distinguished, consisting of a multiple of 250m x 250 m grid cells with unique combinations of soil use, soil type (and related soil properties) and ground water table class. These characteristics determine the parameterization of the CO_2 and CH_4 emissions in the field, element uptake, N transformation processes and adsorption/desorption of phosphate and heavy metals. The model parameters were estimated as a function of land use, soil type and ground water table class, thus allocating them to combinations occurring in distinct plots and the ranges are related to average values for those combinations. In the agricultural plots, a distinction was made in grassland, maize and arable land. Soils were divided in sand, loess, clay and peat. For sand and clay, a further subdivision was made in calcareous and non-calcareous soils, since pH largely affects the uptake and leaching of metals. Furthermore, a distinction was made in different hydrological regimes (wetness classes), using ground water table classes (Gt) from the 1: 50 000 soil map with information on the mean highest water level (MHW) used in the plots, according to: (i) wet (poorly drained): MHW<40cm, (ii) moist (moderately drained): MHW 40-80cm and (iii) dry (well drained): MHW >80cm.

Excretion and housing emissions: In INITIATOR2, excretion of N and P is described by a multiplication of: (i) an excretion factor [kg N or kg P per animal per year] for 65 distinguished animal categories with (ii) the number of animals in each category, based on the geographically explicit system GIAB with available data for each farm in the Netherlands. For heavy metals, the excretion is calculated by a multiplication of: (i) a manure production factor [kg manure/animal per year] for various animal categories with (ii) the number of animals in each category, based on GIAB and (iii) the estimated heavy metal content in each type of manure.

The NH_3, NO_x and N_2O emissions from housing and manure storage systems are described by multiplication of the N excretion with an emission percentage (% NH_3, NO_x or N_2O compared to N excretion). The CH_4 emission from housing and manure storage systems is described quite comparable to NH_3 and N_2O emission. The emissions due to enteric fermentation in animals, occurring both in housing systems and in the field, is calculated by a multiplication of: (i) an emission factor [kg CH_4/animal per year] for 11 main animal categories (aggregated from the 65 original animal categories) with (ii) the number of animals in these in 11 animal categories. The CH_4 emission from animal manure stored in housing and storage systems is calculated by a multiplication of an emission factor [kg CH_4 m^{-3} manure per year] for 7 animal manure categories with the manure volume. The latter amount was calculated by a multiplication of: (i) a manure excretion factor [kg/animal per year] for the distinguished 65 animal categories with (ii) the number of animals in each category and (iii) the reciprocal of the bulk density of the manure [m^3/kg]. Parameters used in the INITIATOR2 model for excretions of N, P and Zn and emissions of NH_3, N_2O and CH_4 and their ranges for the different animal (manure) categories are given in Table I. More details on the parameterization are given in De Vries et al. (2005).

Distribution of nutrients and heavy metals in manure and fertilizers

The production of carbon, nutrients and metals in manure, calculated at farm level is first aggregated to the STONE plot level and then into 31 so-called manure regions in the Netherlands, while distinguishing cattle, pig and poultry manure. These categories, being an aggregation of the 65 animal categories are distinguished because of differences in the availability of N in these manure types for crop uptake. Within a manure region, the manure is distributed depending on land use, soil type and hydrological status. For each land use category, a maximum N application rate was used according to the Dutch/EU legislation, ranging from 250 kg N of animal manure plus 180 kg N in fertilizer for grassland to 170 kg N of animal manure plus 55 kg N fertilizer for arable land on dry sandy soil. Within each region a comparison is made between the maximum acceptable N input and the manure produced by grazing cattle (applied to grassland) and in housing systems. This leads to excess regions, where the available amount of N in manure exceeds the N application limits and shortage regions with a capacity to accept N by animal manure. The excess is distributed over the shortage regions while accounting for distance, the degree of acceptance of additional manure, manure type and a predefined export and processing capacity.

Table I Parameters used in the INITIATOR2 model for excretions of N, P and Zn and emissions of NH_3, N_2O and CH_4 from housing ands manure storage systems, their considered dependence on animal category (in brackets is animal manure category) and housing (stable) type and their overall ranges.

Parameter	Explanation	Range		
		Dairy cattle	Fatten. pigs	Lay hens
$N_{exfactor}$	N excretion per animal (kg $N.animal^{-1}.yr^{-1}$)	30.1-139.1	12.1-30.3	0.31-0.67
$P_{exfactor}$	P excretion per animal ($kgP_2O_5.animal^{-1}.yr^{-1}$)	7.6-42.8	4.6-13.9	0.14-0.64
$Man_{prodfactor}$	Produced fresh manure per animal ($kg.animal^{-1}.yr^{-1}$)	5000-26000	1200-5100	35-88
Zn_{man}	Zn content in animal manure ($mg.kg^{-1}$)	156	564-859	307-386
$frH_{3,em,h}$	Ammonia emission fraction from N excretion (-)	0.044-0.21	0.018-0.303	0.053-0.544[1)]
$frN_2O_{em,h}$	Nitrous oxide emission fraction from N excretion (-)	0.001-0.02[2)]	0.001-0.02[2)]	0.001-0.02[2)]
$CH_{4emfactor,ferm}$	CH_4 emission by fermentation (kg $CH_4.animal^{-1}.yr^{-1}$)	18-102	1.5	0
$CH_{4emfactor,man}$	CH_4 emission from manure (kg $CH_4.m^{-3}$ $manure.yr^{-1}$)	0.7-3.5	3.0	4.1

[1] The low values are related to low emission housing systems
[2] The used values are 0.001 for slurry and 0.02 for solid manure, independent of the type of manure

The amount of manure that cannot be applied in the shortage areas is applied in the excess manure region were it was produced, with highest excess in STONE plots with the highest production, implying a violation of the N application limits in these plots. The application of P and metals is derived by using the weighted average N/P and N/metal ratios in the manure for the corresponding region. The inorganic N and P fertilizer application is calculated by the difference between the maximum allowable N input (animal manure + fertilizer) and the calculated amount of applied animal manure. When the applied amount of animal manure exceeds the application limits the fertilizer amount was set to zero. More details on the approach are given in De Vries et al. (2005).

CO_2 and CH_4 soil emissions: The CO_2 emission is calculated as the sum of the: (i) net C pool change in mineral agricultural soils, (ii) net C release due to oxidation in peat soils and (iii) net C release due to liming caused by acidification of agricultural soils. In the Netherlands, about 20 percent of the grasslands are found on drained peat soils. Drainage of peat soils results in oxidation of soil organic matter and CO_2 emission (Langeveld et al., 1997). The net C pool change in mineral agricultural soils is calculated as the difference in annual C input by animal manure, compost and crop residues and the annual C release due to oxidation of both the incoming C and the available C in the soil. The net C release due to oxidation of peat soils, which is the most important source of CO_2, is calculated by a multiplication of: (i) the annual lowering of the peat soil as a function of the ground water level ($mm.yr^{-1}$) with (ii) the bulk density of the peat soil ($kg.m^{-3}$) and (iii) the fraction of organic carbon in the peat. The net C release due to liming is calculated by predicting the liming requirement from

the fate of added nitrogen and base cations in manure and fertilizer. More details for all these processes are given in De Vries et al. (2005). The CH_4 emission from terrestrial systems is set at a constant average value with the exception of natural grasslands that emit CH_4 at a rate depending on the ground water level (Van den Pol-van Dasselaar et al., 1999). More details are given in De Vries et al. (2005).

NH_3 and N_2O soil emissions and N leaching and runoff: The various N fluxes from and in agricultural soils are calculated with a consistent set of simple linear equations (De Vries et al., 2003). First the total N input to the soil is calculated as the sum of inputs by animal manure, fertilizer, atmospheric deposition and biological N fixation. The fate of N in soils is calculated as a sequence of occurrences in the order ammonia emission, followed by N uptake, N mineralization/ immobilization, nitrification and denitrification in the soil. All N transformation processes are a linearly function of the inflow of N, namely: (i) the N input to the soil ammonia emission to, (ii) the (effective) N input minus the NH_3 emission for N uptake (N removal from the field), (iii) the net N input (N input minus NH_3 emission minus N uptake) for N mineralization/ immobilization, (iv) the net N input minus N mineralization/immobilization for nitrification and the nitrification flux for denitrification.

The NH_3 emissions from soils are calculated by a multiplication of the N inputs by manure and fertilizer application and grazing cattle with specific N emission fractions for these inputs. Maximum N uptake rates (at sufficient N supply) are given as a function of land use (in our study grass, maize and arable land using a mixture of wheat, other cereals, potatoes, sugar beet and other crops), soil type (sand, loess, clay and peat) and ground water table (dry, moist and wet) in terms of a maximum yield and related N contents. The uptake and soil N transformation fractions are given as a function of land use, soil type and/or hydrological regime. The flux of N leaving the terrestrial system is calculated by subtracting all N outputs from the system (emission, uptake and denitrification) from the N inputs to the soil, while accounting for the net mineralization or immobilization. The leaching loss from the terrestrial systems is partitioned to surface water and to groundwater by multiplying the leaching loss with a runoff fraction (including all pathways for N moving to surface waters) and a leaching fraction (1 – runoff fraction), respectively.

The N_2O and NO_x emission from soils are calculated as the multiplication of specific N_2O and NO_x emissions fractions with the nitrification flux and denitrification flux. IMITIATOR also calculates N immobilization/ mineralization in surface water and nitrification and denitrification in ground water, ditches and surface water and the related N_2O emissions. In this paper, the N fluxes are however limited to those occurring in agricultural soils.

An overview of major parameters describing the various N transformations and transfers in the soil and their ranges in average values is given in Table II. N uptake is actually described as a minimum N uptake (related to mineralization of soil organic matter) and a fraction of the effective N input. Maximum N uptake rates (at sufficient N supply) are given as a function of land use (in our study grass, maize and arable land using a mixture of wheat, other cereals, potatoes, sugar beet and other crops), soil type (sand, loess, clay and peat) and ground water table (dry, moist and wet) in terms of a maximum yield and related N contents. The model parameters related to N transformations were based on literature data, field observations, results from more detailed model calculations and expert judgment (De Vries et al., 2003).

Table II Major N transformation parameters used in the INITIATOR2 model for agricultural soils, their considered dependence on land use, soil type and hydrology and their overall ranges (De Vries et al., 2003).

Parameter	Explanation	Land use	Soil type	Hydrology	Range
$frNH_{3,em,a}$	Ammonia emission fraction from manure applied to land (-)	x	x	-	0.05-0.10
$frNH_{3,em,g}$	Ammonia emission fraction from dung and urine from grazing animals (-)	-	-	-	0.08
$frNH_{3,em,f}$	Ammonia emission fraction from fertilizer (-)	-	-	-	0.02
frN_{up}	N uptake fraction	x	x	x	0.25-0.50
$N_{up,max}$	Maximum net nitrogen uptake in crops removed from the field (kg.ha^{-1}.yr^{-1})	x	x	x	110-340
$fr_{ni,s}$	Nitrification fraction for the soil (-)	x	x	x	0.85-0.99
$fr_{de,s}$	Denitrification fraction for the soil (-)	x	x	x	0.35-0.94
frN_2O_{ni}	Fraction relating N_2O emissions to total nitrification to (-)	-	x	-	0.01-0.02
frN_2O_{de}	Fraction relating N_2O emissions to total denitrification to (-)	-	x	-	0.03-0.07

Phosphorus and heavy metal behavior: The accumulation or release of P is calculated from a mass balance, subtracting P uptake by plants, leaching to groundwater and runoff to surface water from the P input by manure and fertilizer. In INITIATOR2, the root zone in agricultural soils is divided in three layers of 0-5cm, 5-20 cm and 20-50 cm. The P mineralization rate is related to the C mineralization rate in mineral and organic (peat) agricultural soils using an average P/C ratio. P uptake is calculate by multiplying the yield, that depends on land use, soil type, ground water table and N input as described before, with a constant P content in the crop. P leaching is described by a multiplication of the water flux with a dissolved P concentration, which is related to amount of reversibly adsorbed P in the soil according to a Langmuir adsorption equation. The maximum amount of reversibly adsorbed P (mmol kg^{-1} P), $P_{re, max}$, was related to the amount of oxalate extractable Al and Fe, $(Al+Fe)_{ox}$, according to $P_{re,max} = 1/6\ (Al+Fe)_{ox}$ (Van der Zee, 1988; Schoumans and Groenendijk, 2000). Actually, the reaction of inorganic P in soil is characterized by a fast reversible process and a slow, almost irreversible, process which causes the hysteresis effect of phosphate sorption and desorption (Van der Zee, 1988). The model also accounts for the possibility of irreversible adsorption by using a Freundlich adsorption model, only including the possibility of adsorption and not of desorption. As with reversibly adsorbed P, the maximum amount of irreversibly adsorbed (diffused or precipitated) P, $P_{ir,max}$, was related to the amount of oxalate extractable Al and Fe, according to $P_{ir,\ max} = 1/3\ (Al+Fe)_{ox}$ (Van der Zee, 1988; Schoumans and Groenendijk, 2000). More details on the process descriptions are given in De Vries et al. (2005).

As with phosphorus, heavy metal (Pb, Cd, Cu and Zn) accumulation is calculated from a mass balance, subtracting metal uptake and metal leaching to groundwater (including runoff to surface water) from the metal input. In this paper, we focused the calculation on zinc, being a heavy metal that is mainly supplied to agricultural soils by animal manure. The Zn fluxes included in the calculation were all major Zn inputs (fertilizer, animal manure, food concentrates and atmospheric deposition) and outputs (crop and animal products; leaching). The possible impact of soil erosion was neglected since all sites are located in flat areas (De Vries et al., 2004). The net zinc uptake rate was derived by multiplying the yield of the crop considered by the zinc content in that crop. For the assessment of Zn concentrations in plants, a non-linear (Freundlich) type relation between the Zn concentration in the plant and the Zn concentration in the soil (soil-plant relationship) was used based on a dataset for the considered crops. The soil plant transfer constant K_{sp} is calculated as a function of the content of organic matter, clay and pH. Values for the various coefficients were derived for Zn in the crops considered, being grass, maize and crops considered representative for arable land (wheat, potatoes and sugar beet). The Zn leaching rate from the topsoil was derived by multiplying the precipitation excess with a dissolved Zn concentration, which was related to the reactive soil Zn concentration according to a Freundlich equation in which the Freundlich coefficient, K_f, is also calculated as a function of the content of organic matter, clay and pH-H_2O. Values for the various regression coefficients were derived from laboratory experiments with approximately 1400 soil samples from Dutch locations. Since the data on present Zn contents in soil refer to total concentrations, the reactive concentrations were derived from total concentrations ((De Vries et al., 2004).

An overview of major parameters describing the various P and Zn transformations and transfers in the soil and their ranges in average values is given in Table III. In this study, the model was applied for the rooting zone for N and P and for the plough layer of 0-30cm in the case of heavy metals. Data on the content of P and of Fe and Al-hydroxides were based on a detailed profile description for major soil types in each plot. Each plot also has a detailed hydrological schematization down to 5 meters below the soil surface. For each distinguished layer, both vertical and lateral water fluxes are distinguished and quantified in mm water $year^{-1}$. For this application, only data from the topsoil were used using a 30-year average hydrology. Data on the Zn content were derived from 2865 individual soil samples in Provincial monitoring Networks and a National Soil Monitoring network. The interpolation of those data to the considered plots was derived by a geostatistical interpolation method (De Vries et al., 2004). Both the soil plant transfer constant for Zn, K_{sp}, and the Freundlich coefficient for Zn adsorption, K_f, were calculated as a function of soil properties (Table III). Data on organic matter content, clay content and pH-KCl were based on the Dutch Soil Information System (Bregt et al., 1986).

Table III Major P and Zn parameters used in the INITIATOR2 model for agricultural soils, their considered dependence on land use, soil type and hydrology and their overall ranges (De Vries et al., 2005).

Parameter	Explanation	Land use	Soil type	Hydrology	Range
P_{re}	Amount of reversibly adsorbed P (mmol kg^{-1} P)	(x)	(x)	(x)	10-45[1)]
K_L	Langmuir adsorption constant for P (m^3 mol^{-1})	-	-	-	35
$Zn_{soil,tot}$	Total concentration of Zn in the soil ($mg.kg^{-1}$)	(x)	(x)	(x)	34-143[1)]
K_{sp}	Soil plant transfer constant for Zn ($mg.kg^{1-n}$)	-	x	-	Varying with pH, clay, OM
K_f	Freundlich coefficient for Zn ($mol.l^{-1n}.kg^{-1}$)	-	x	-	Varying with pH, clay, OM

[1)] These inputs were derived from geo-referenced databases, indirectly accounting for a dependence on land use, soil type and hydrological regime.

Included measures and their parameterization

In this study we investigated the impact of various management measures (good agricultural practices) and technical measures (mostly changes in housing systems) to reduce nutrient inputs and ammonia emissions as summarized in Table IV. Most measures focus on mitigation of the emission of N compounds to the atmosphere and leaching and runoff of N to ground water and surface water with a specific focus on NH_3 emission. This refers to covering of manure storage systems, low emission application, reduce grazing time and low emission housing systems (measures 6-10 and 14). All other measures, apart from 13, influence the net input of N. Thereby, the net input of P and Zn is also reduced. The measures leading to reduction in livestock (measure 1) and a change in animal manure production (measure 2 and 7) also reduce the CH_4 emission. The parameterizations of effects for N compounds (Kros et al., 2003) are often based on expert judgment. The same is true for the related changes in the other compounds, in this case CH_4, P and Zn. This study should thus be seen as an exploratory analyses to get quantitative insight in the effects of the measures aiming at reducing N emissions on emissions of CH_4 and on soil accumulation and leaching/runoff of P and Zn.

Table IV. Management measures (good agricultural practices) and technical measures (mainly related to animal housing practices) that were evaluated with INITIATOR2

Nr	Measure	Type[1)]	Explanation[2)]
1	Decrease livestock intensity	GAP/TM	Ongoing process due to actual policy
2	Improving animal feeding	GAP	Enhancing N and P efficiency
3	Reducing fertilizer use	GAP	Due to a better use of fertilizers and animal manure through precision agriculture
4	Apply cover crops	GAP	On arable land more N, P and Zn will be taken up.
5	Optimal drainage	GAP	Irrigation of dry soils and draining very wet soils will result in higher uptake of N, P and Zn.
6	Low emission application of animal manure and cover manure reservoirs	GAP	Results in a lower NH_3 emission fraction for application and storage
7	Reduce grazing time	GAP	Leads to moving of manure from stable to pasture. Reduces NH_3 emission (if low emission housing is applied) and N leaching
8	Low emission housing	TM/GAP	Lower NH_3 emission fractions from stables and manure storage systems within pig and poultry husbandry, according to Dutch policy rules
9	Extremely low emission pig and poultry husbandry	TM	Apply lowest NH_3 emission fractions possible for pig and poultry farms.
10	Extremely low emission housing for dairy farms	TM	Apply lowest NH_3 emission fractions possible for dairy farms
11	Manure processing	TM	Processing the manure surplus without any emission losses
12	Improving workability factor of animal manure	TM	Increase N and P efficiency and causes a lower N and P input by fertilizer
13	Buffer strip	TM	Manure and fertilizer free zones along drainage canals. Reduces runoff of N.
14	Emission free pig and poultry husbandry	TM	Remaining pig and poultry are staying in NH_3 emission free stables and all manure is processed and transported (target for 2030)

1) GAP: good agricultural practice (management measures); TM: technical measure
2) Background information and parameterization is given in (Kros et al., 2003).

RESULTS AND DISCUSSION

Atmospheric emissions of ammonia, nitrous oxide and methane.
An overview of the estimated emissions of NH_3, N_2O and CH_4 in the year 2000 (reference year) and after the implementation of measures is presented in the Table V. The results show that CH_4 and, to a lesser extent, NH_3 emissions predominantly occur from housing and manure storage systems, whereas N_2O emissions are fully dominated by soil emissions. Actually the CH_4 emissions from the field are due to enteric fermentation, leading to direct emissions from the cows grazing in the field and not form the agricultural soil itself. Soils, were a small net sink of CH_4 (-0.1 kton.yr^{-1}).

Table V Estimated emissions of NH_3, N_2O and CH_4 (kton.yr^{-1}) from both housing/manure storage systems and agricultural soils after a 30-year period in Dutch agricultural soils using the inputs for the year 2000 (SR=standard run) and after implementation of management measures (GAP = Good agricultural practices) and technical measures (PTM= *Plus* technical measures), using INITIATOR2.

System	Emissions (kton.yr^{-1})								
	NH_3			N_2O			CH_4		
	SR	GAP	PTM	SR	GAP	PTM	SR	GAP	PTM
Housing System	81	49	22	2.0	1.7	1.3	304	254	246
Agricultural soil[1]	60	23	19	32	17	15	108	52	52
Total	141	72	41	34	19	16	416	306	298

[1] including CH_4 emission from grazing cattle (enteric fermentation)

Implementation of good agricultural practices is calculated to decrease the NH_3 and N_2O by nearly a factor of two, whereas the CH_4 emissions to air are reduced by approximately 25% (Table V). The reason for the lower effect on CH_4 is because only the measures leading to reduction in life stock (measure 1) and a change in animal manure production (measure 2) reduce the CH_4 emission. No measures that specifically reduce CH_4 emissions, such has modifications in rations and manure storage, have been calculated. The reduction in emission from both the housing system and the soil is relatively larger for NH_3 (approximately 70%) than for N_2O (approximately 50%), which is to be expected since part of the measures (6-8) focus only on the fate of NH_3. Nevertheless, the reduction is also quite large for N_2O emission since the measures lead a strong reduction in the net N input thus reducing the soil emissions that are dominant in the case of N_2O (Table V). After implementation of GAP, NH_3 emissions approached the required 100 kton.yr^{-1} for the year 2010, but not the required 50 kton.yr^{-1} for the year 2030. A 6% reduction in N_2O emission is also attained.

The additional implementation of technical measures only have a strong effect on the NH_3 emission from the housing systems, to which most of the measures were focused (measure 9,10 and 14). The effect on the N_2O emission is limited since the net N input to the field is only slightly reduced (see also Table V), which is mainly due to measure 14 (remaining pig and poultry are staying in NH_3 emission free stables and all manure is processed and transported). The latter measure also causes a very slight reduction in CH_4 emission (Table V), but the effect is very small, since it only affects the CH_4 emissions from stored manure.

Element budgets for nitrogen, phosphorus and zinc

The accumulation and leaching/runoff of N, P and Zn from agricultural soils in the year 2000 and the impacts of good agricultural practices and technical measures on these element budgets are presented in Table VI. For all the elements, the net uptake, due to removal of the harvested biomass from the field, is about half of the input, whereas the sum of leaching to ground water and runoff to the ditches varies between 15-20% of the total input using the inputs for the year 2000 (standard run). Accumulation of P and Zn due to net adsorption is approximately 35% of the input for both elements for the standard run. In case of N there is a net source due to net mineralization of peat soils

(Van Kekem, 2004). The relatively low leaching and runoff is due to denitrification, being approximately 50% of the net N input.

Table VI Estimated element balances of N, P and Zn (kton.yr^{-1}) from agricultural soils after a 30-year period in Dutch agricultural soils using the inputs for the year 2000 (SR=standard run) and after implementation of management measures (GAP = Good agricultural practices) and technical measures (PTM= *Plus* technical measures), using INITIATOR2.

Flux type	Annual flux (kton.yr^{-1})								
	N			P			Zn		
	SR	GAP	PTM	SR	GAP	PTM	SR	GAP	PTM
Input[1]	931	572	533	100	59	56	1.81	1.16	1.09
Net uptake	402	333	336	49	40	40	0.85	0.72	0.69
Denitrification	435	228	195	-	-	-	-	-	-
Accumulation	-49	-46	-46	38	9.0	5.5	0.64	0.16	0.12
Runoff	52	26	15	1.1	0.77	0.73	-	-	-
Leaching	90	31	33	12	9.5	9.3	0.32[2]	0.28[2]	0.28[2]

[1] In case of N, the NH_3 emission in the field (see Table IV) is already subtracted from the input.
[2] Including runoff

Impacts of management measures lead to a reduction of approximately 40% in the net N input (N input to the field minus the NH_3 emission in the field) and in P and Zn input. The reduction in the uptake of N, P and Zn is relatively limited (15-18%) and is due to a decrease in yield and in case of Zn also in Zn contents. The release by net N mineralization hardly changes, since this process is yet limited to the mineralization in peat soils. The reduction in denitrification is comparable to the reduction in net N input (nearly 50%), thus leading to a comparatively high reduction in the leaching to ground water and runoff to the ditches. The sum of both fluxes is approximately 10% of the total input after implementation of GAP, compared to 15% when using the inputs for the year 2000 (standard run). In case of P and Zn, the relative reduction in accumulation (75-80%) is much higher than the relative reduction in net input (40%). Consequently, the sum of the leaching to ground water and runoff to the ditches compared the total input increases for those elements from approximately 16 to 20% for P and from 18 to 24% for Zn (Table V). The remaining reduction in element inputs by technical measures is small, since these measures were mainly focused on NH_3 emissions from the housing system. The measures mainly affect the ratio of runoff and leaching for N (mainly because of measure 13: buffer strip). It hardly affects, however (the ratio of) runoff and leaching for P and Zn since the outflow of these elements is mainly determined by the soil pool and not by the input during the simulation period. The reduced inputs of those elements are mainly accounted for by a reduced soil accumulation (Table VI).

Concentrations of nitrogen compounds, phosphorus and zinc in soil and water

The average concentrations of nitrate (nitrogen), phosphate and zinc in soil, soil solution, ground water or surface water and their 90 percentile ranges for the standard run and the impacts of management measures (GAP) and technical measures on these concentrations are presented in Table VII.

Table VII Calculated annual average concentrations and their 95 percentile ranges of nitrate (nitrogen), phosphate and zinc in soil, soil solution, ground water or surface water in Dutch agricultural soils after a 30-year period using the inputs for the year 2000 (SR=standard run) and after implementation of good agricultural practices and technical measures, using INITIATOR2.

Scenario	$[NO_3]$ in leachate to ground water (mg.l^{-1})	[N] in runoff to surface water (mg.l^{-1})	P_{ox} in soil (mmol.kg^{-1})	[P] in runoff to surface water (mg.l^{-1})	Zn in soil (mg.kg^{-1})	[Zn] in soil solution (µg.l^{-1})
Standard run	51 (0.17-254)	6.0 (0.70-27)	21 (6.6-61)	0.74 (0.21-1.1)	73.5 (34-140)	54 (2.8-135)
Good agricultural practices	17 (0.15-80)	2.8 (0.30-15)	20 (4.4-56)	0.68 (0.20-1.0)	69.0 (33-127)	48 (2.7-118)
Plus Technical measures	17 (1.6-74)	1.7 (0.13-11)	19 (4.2-55)	0.67 (0.20-1.0)	68.6 (32-125)	47 (2.7-115)
Limits	50[1]	2.2[2]	-	0.15[2]	94-179[3]	8.8-42.8[2,3]

[1] The critical limit refers to $[NO_3]$ in drinking water, also being used for upper ground water
[2] The critical limit refers to [N], [P] or [Zn] in surface water
[3] The critical limit varies since it is based on an added risk principle, adding a maximum permissible addition to a natural background concentration in soil or surface water (De Vries et al., 2004).

The calculated annual average concentrations after a 30-year period are exceeding critical limits in either leachate to ground water (NO_3), runoff to surface water (N and P) or soil solution (Zn) when using the inputs for the year 2000. The exceedance is largest for P and followed by N and Zn, whereas the annual average value is almost equal to the critical limit for NO_3. The variation in concentrations is however large, as can be seen from the 90 percentile ranges in Table VI. The critical limits are hardly exceeded on clay and peat soils in the case of N and Zn (values near the lower 5 percentile), whereas the exceedance is very large for N in the dry sandy soils, for P in the wet sandy soils and for Zn in the non-calcareous sandy soils (values near the upper 95 percentile).

Good agricultural practices lead to very strong reductions in the concentration of NO_3 in leachate to ground water (66 %) and of N in runoff to surface water (54 %). Even then, however, there are still plots exceeding the critical limit for nitrate in ground water, specifically below the well-drained sandy soil, where concentrations are generally highest (e.g. Fraters et al., 2001). In line with other studies (e.g. Schoumans and Groenendijk (2000) for P and De Vries et al. (2002) for metals), the reductions of P in runoff to surface water (15%) and of Zn in soil solution (7%) are comparatively low, showing that their behavior even after a 30-year period is mainly governed by the P and Zn pool in the soil, which hardly change in that period (Table VI). However, the steady state Zn concentration in soil and soil solution, that is reached in a period of several hundred (sandy soils) to thousands of years (clay soils; De Vries et al. (2004) is strongly influenced by good agricultural practices. The average steady state soil Zn concentration is 113 mg.kg^{-1} for the present situation (standard run) and 57 mg.kg^{-1} when good agricultural practices are applied. Similarly, the average value for the dissolved Zn concentration is 262 µg.l^{-1} for the standard run and 169 µg.l^{-1} after the application of all management measures.

Technical measures mainly affect the N concentrations in runoff to surface water due to a buffer strip (measure 13). As expected, these measures and also GAP have much less on P and Zn concentrations than on N concentrations within the considered time frame of 30 years even though the P and Zn accumulation is strongly reduced. Additional measures, specifically focused on P and Zn, such as buffer zones near ditches (e.g. by addition of Al and Fe hydroxides) or removal by phytoremediation, are needed to reach the water quality targets.

CONCLUSIONS

It should be noted that this paper only presented the results of all management measures and technical measures for the whole of the Netherlands. Taking all measures together, there is always a positive effect of measures related to N reduction to other emissions, but in certain cases the effect is not positive. For example, the reduction of grazing causes less N leaching but increases the emission of NH_3 and CH_4, unless you use low emission housing systems. Furthermore, the average results can strongly vary over soil types and drainage types. In general, however, the following conclusion can be drawn from this study:

- The present (year 2000) production and input of animal manure and fertilizer causes substantial atmospheric emissions of NH_3, N_2O and CH_4 and causes leaching and runoff of N, P and Zn to such an extent that critical limits in either (leachate to) ground water (NO_3), (runoff to) surface water (N and P) or soil solution (Zn) are exceeded, specifically in sandy soils .
- Good agricultural practices related to the reduction of N inputs strongly reduces the emissions of NH_3 and the leaching and runoff of NO_3 (N). It also strongly reduces emissions of N_2O and the accumulation P and Zn due to a reduced P and Zn input. The emissions of CH_4 are less affected and the effect is small on the leaching and runoff of P and Zn.
- Technical measures, focusing on the reduction of emissions of NH_3 only slightly affect the emissions of N_2O and CH_4.

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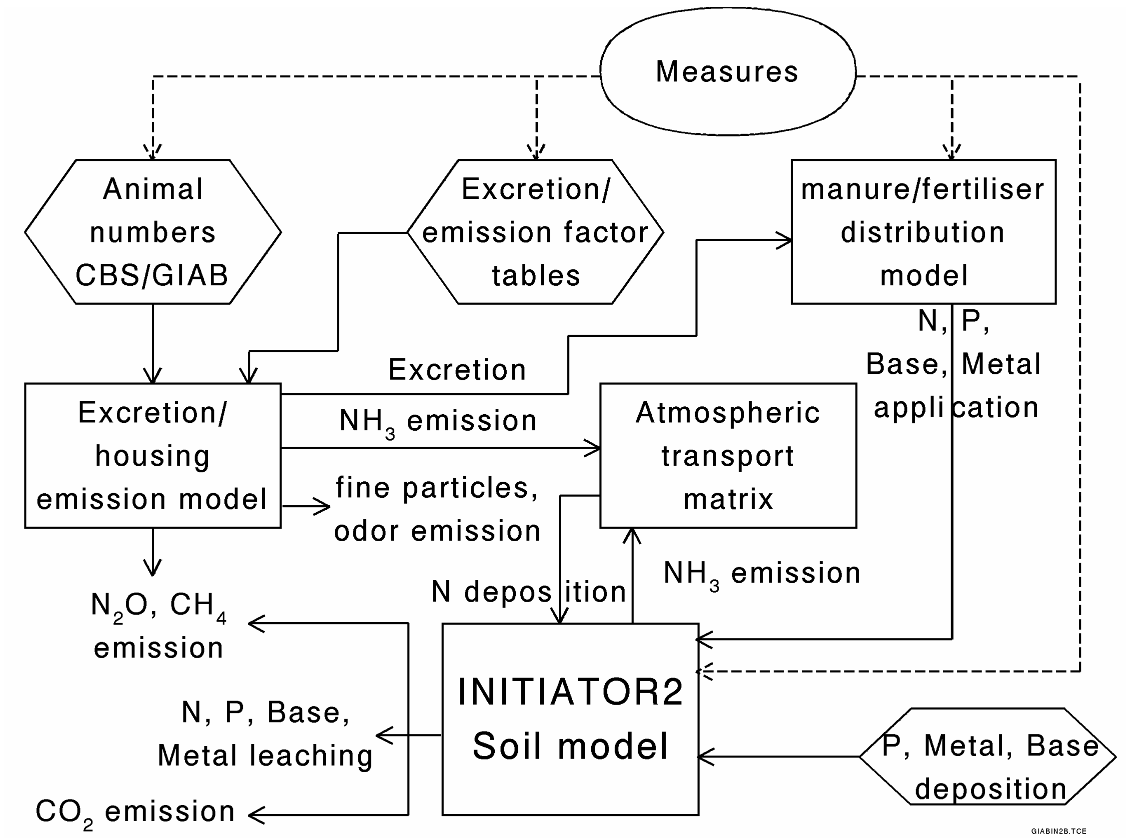

Figure 1 Coupling of modules and model outputs in INITIATOR2 model for agriculture