A DECISION SUPPORT SYSTEM FOR THE INTEGRATED EVALUATION OF AGRICULTURAL MANAGEMENT ON ENVIRONMENTAL QUALITY

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ABSTRACT
Excess nitrogen inputs by animal manure and fertilizer in the Netherlands do cause various effects, such as (i) decreased plant species diversity of terrestrial ecosystems by eutrophication and acidification induced by elevated N deposition, (ii) decreased water quality and species diversity of aquatic ecosystems and eutrophication of coastal systems, mainly induced by runoff of N, (iii) high NO_3 concentrations in groundwater, used as drinking water with potential health impacts and (iv) elevated N_2O emissions causing climate change. Apart from N emissions, excessive manure inputs also cause emissions of other greenhouse gases, mainly methane (CH_4), and accumulation and/or elevated leaching of various compounds to ground water and surface water. This paper presents an overview of the integrated model system IMITATOR predicting: (i) emissions of ammonia and greenhouse gases (CO_2, CH_4 and N_2O) from animal housing systems, agricultural land and drained 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. Results of various mitigation measures in view of reducing emissions of nitrogen compounds to air, ground water and surface water, including improved farming practices and structural changes in agriculture, do have a positive spinoff on the emissions or accumulation of other compounds as illustrated in the paper.

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 [1]. These enhanced levels of reactive nitrogen in the environment (in air, soil, ground water and surface water) lead to a cascade of effects [2]. Observed effects in the Netherlands, for which different targets are defined, include [3]:

(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).
(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 N emissions, excessive manure inputs also cause emissions of other greenhouse gases, mainly methane (CH_4), and accumulation and/or elevated leaching and runoff of various compounds, including carbon, nutrients (nitrogen, phosphate and base cations) and metals from agricultural soils to ground water and surface water. Analogous to N_2O, approximately half of the emission in the Netherlands stems from agriculture [4] and the net contribution to the warming potential is of even greater importance. Changes in carbon are relevant in view of soil fertility and the role of the soil as a net sink or source of CO_2. Together with N, P is generally considered to be the key element controlling the productivity of fresh waters. The potential impacts of P loads by manure on agricultural soils on the eutrophication of surface water is thus a major concern in the Netherlands [5, 6]. Recently, the contribution of metals in agricultural soils to the leaching and runoff to ground- and surface water has also become of concern as it does have large impacts on the water quality [7].

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 to avoid adverse impacts (specifically in view of biodiversity) on natural ecosystems. Considering an estimated annual ammonia emission in the Netherlands in 1995 of 175 Gg NH_3 [8], this implies a succeeding decrease in ammonia emissions of approximately 45%, 70% and 80% compared to this target year. The emission target for N_2O is a 6% decrease compared to 1995, 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 $mg.l^{-1}$ and the N concentration in stagnant surface waters below a target concentration of 2.2 $mg.l^{-1}$. The P concentration in surface waters should stay below a concentration of 0.15 $mg.l^{-1}$ and concentrations of the heavy metals Pb, Cd, 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, atmospheric 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 application simultaneously, an integrated model IMITATOR was developed [9]. The policy aim of IMITATOR (Integrated Manure 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. The relevant fluxes include:

- all reactive nitrogen fluxes, i.c. ammonia emission, nitrate leaching to ground water, runoff of nitrogen to surface water and nitrous oxide emission to the atmosphere (focus of the original model INITIATOR)
- atmospheric emission of greenhouse gases (CO_2, CH_4, N_2O) from housing systems and terrestrial ecosystems.
- soil accumulation/release, leaching and runoff of phosphate, base cations (Ca, Mg, K) and heavy metals to ground water and surface water.

This paper provides an overview of the integrated model system and a demonstration how the model can be used for the evaluation of mitigation measures in terms of emissions of nitrogen compounds, green house gases, phosphate and metals to air, ground water and surface water. In this paper we limit the results to atmospheric emissions of NH_3, N_2O and CH_4 and to the accumulation and leaching/runoff of N, P and Zn, being a heavy metal that is mainly supplied to agricultural soil by animal manure.

MODELLING APPROACH

A flow chart of the considered element inputs and element transformation processes in the model IMITATOR (Integrated Manure Impact Assessment Tool On a Regional scale) is given in Figure 1. The flow chart is limited to the agricultural part of IMITATOR.

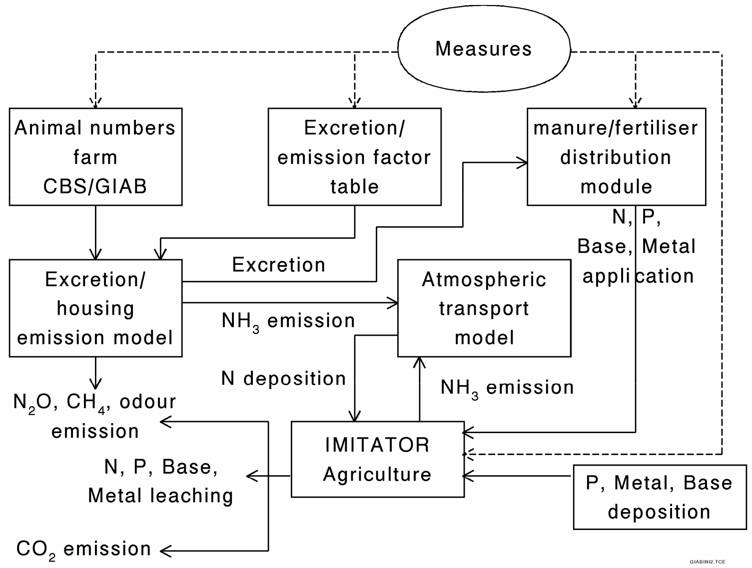

Figure 1 Coupling of modules and model outputs in IMITATOR agriculture

A so-called CBS/GIAB database contains animal numbers for each farm in the Netherlands. The NH_3, NO_x, N_2O, CH_4 and odour emissions from housing and manure storage systems are described by a multiplication with excretion factor and/or emission factor for different animal categories, depending on the type of emission (a maximum of 65 categories in case of N excretion and NH_3 emission). Results of the N, P and metal excretion are input for a simple manure transport model predicting manure export from intensive animal husbandry areas and manure import in less intensive areas. This module also calculates the related fertilizer use. NH_3 emissions due to N input by manure application and grazing are calculated in the core of IMITATOR. Together with NH_3 emissions from housing systems, it forms the input of a simple atmospheric transport model (a transfer matrix based on results of the detailed OPS model). In the core of IMITATOR the emissions of CH_4, CO_2 and N_2O 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 are also calculated. Measures can affect both animal numbers (CBS/GIAB database), excretionfactors or emissionfractions (changes in table) or parameters in IMITATOR influencing the fate of element in soil, ground water and surface water (see Figure 1).

IMITATOR 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 [10], (ii) calculate 'regional specific nitrogen ceilings' (maximum amounts of reactive nitrogen that does not lead to exceedance of critical limits or targets) [11] and (iii) assess the impacts of improved farming practices and structural changes in agriculture on nitrogen fluxes in the Netherlands [12]. INITIATOR is a simple N balance model based on empirical linear relationships between the different N fluxes. We have chosen for a simple approach to maintain transparency and to be able to apply the model with available data. The processes and fluxes treated in agricultural soils in INITIATOR are [10]:

- NH_3, NO_x and N_2O emission from housing and manure storage systems and from soils due to the application of animal manure, fertilisers and dung and urine from grazing animals.
- Uptake, immobilisation/mineralisation, nitrification and denitrification in soil followed by N leaching to ground water and runoff to surface water. NO_x and N_2O emissions are related to nitrification and denitrification.

Starting with INITIATOR, the extensions included in IMITATOR (Integrated Manure Impact Assessment Tool On a Regional scale) are [9]:

- Methane (CH_4) emission from housing and manure storage systems and terrestrial ecosystems.
- CO_2 emission from terrestrial ecosystems, with a specific focus on degradation of peat soils.
- Posphorous leaching to groundwater and runoff to surface water, including P uptake and P adsorption/desorption in soil.

- Metal (Pb, Cd, Cu and Zn) leaching from the rootzone and accumulation in soil, including metal uptake and metal adsorption/desorption in soil.
- Base cation leaching (specifically Ca) from the rootzone in view of soil acidification and related liming requirements.

A full description of all the process descriptions in IMITATOR are given in De Vries et al. (2004) [9].

MODEL APPLICATION

Schematisation of the study area and model parameterization

In this study, IMITATOR was applied to all agricultural soils in the Netherlands. For agriculture, a total number of 4647 plots were distinguished, consisting of a multiple of 500x500 m^2 grid cells with unique combinations of soil use, soil type (and related soil properties) and ground water table class, which determine the parameterisation of CO_2 and CH_4 emissions in the field, N transformation processes and uptake and adsorption or desorption of phosphate and heavy metals. Geo-referenced data for the N input via animal manure and fertilisers were based on data statistics at farm level for the year 2000, using the GIAB/CBS 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 1km x 1km grid scale for N and a 10km x 1km grid scale for Zn. N fixation was estimated as a function of land use [8]. Parameters used in the IMITATOR model for excretions of N, P and Zn and emissions of NH_3, N_2O and CH_4 and the ranges in average values for the different animal (manure) category and housing (stable) types are given in Table 1.

Table 1 Parameters used in the IMITATOR 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 (manure) category and housing (stable) type and their overall ranges

Parameter	Explanation	Animal category	Housing type	Animal manure category	Range
$N_{exfactor}$	N excretion per animal (kg $N.animal^{-1}.yr^{-1}$)	x			0.31-139.1
$P_{exfactor}$	P excretion per animal ($kgP.animal^{-1}.yr^{-1}$)	x			0.14-42.8
$Man_{prodfactor}$	Produced fresh manure per animal ($kg.animal^{-1}.yr^{-1}$)	x			25.4-2600
Zn_{man}	Zn content in animal manure			x	156-859
$frH_{3,em,h}$	Ammonia emission fraction from N excretion (-)	x	x		0.13-0.28[3)]
$frN_2O_{em,h}$	Nitrous oxide emission fraction from N excretion (-)	x	x		0.13-0.28[3)]
$CH_{4emfactor,ferm}$	CH_4 emission by fermentation (kg $CH_4.animal^{-1}.yr^{-1}$)	x			8-102
$CH_{4emfactor,man}$	CH_4 emission from manure (kg $CH_4.m^{-3}$ $manure.yr^{-1}$)			x	0.7-4.1

An overview of major parameters describing the various element transformations and transfers in the soil, limited to those used in this study, and their ranges in average values is given in Table 2. 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.

Table 2 Major parameters used in the IMITATOR model for agricultural soils, their considered dependence on land use, soil type and hydrology and their overall ranges [8].

Parameter	Explanation	Land use	Soil type	Hydrol.	Range[1]
N transformation data					
$frNH_{3,em,a}$	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
$N_{up,max}$	Maximum net nitrogen uptake in crops removed from the field ($kg.ha^{-1}.yr^{-1}$)	x	x	x	110-340
fr_{up}	Nitrogen uptake fraction (-)	x	-	-	0.25-0.50[2)]
$fr_{ni,s}$	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 total nitrification to N_2O emissions (-)	-	x	-	0.01-0.02
frN_2O_{de}	Fraction relating total denitrification to N_2O emissions (-)	-	x	-	0.03-0.07
P and metal (Zn) behaviour data					
P_{re}	Amount of reversibly adsorbed P ($mmol\ kg^{-1}$ P)	(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)	-	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
Hydrological data					
P	Precipitation ($mm.yr^{-1}$)				705-874[1)]
E_s	Soil evaporation ($mm.yr^{-1}$)	x	-	-	90-165
E_t	Transpiration ($mm.yr^{-1}$)	x	x	x	144-388
fr_{int}	Interception fraction (-)	x	-	-	0.02-0.12
fr_{ro}	Runoff (lateral flow) fraction (-)	-	x	x	0.05-0.95

[1)] These inputs were derived from geo-referenced databases, without a direct dependence on land use, soil type and hydrological regime. Values in brackets show which aspect has the largest impatc on its value.

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.

In this study, the model was applied for the rooting zone and in the case of heavy metals it was even lited to the ploughlayer of 0-30cm. Data on organic matter content, clay content and pH-KCl were based on the Dutch Soil Information System. 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 STONE plots was derived by a geostatistical interpolation method. 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 STONE plot. Each plot also has a detailed hydrological schematization down to 5 meters below the soil surface [13]. 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. Model parameters related to N transformations were based on literature data, field observations, results from more detailed model calculations and expert judgement [8].

Included measures and their parameterization

In this study we investigated the impact of measures related to good farming practices, aiming at a more efficient nutrient use and structural changes in agriculture to reduce nutrient inputs and ammonia emissions. The various measures are summarized in Table 3. Originally, the impact of those measures was investigated with the INITIATOR model, focusing on the emission of NH_3 and N_2O to the atmosphere and leaching and runoff of N to ground water and surface water [14]. The measures were also originally developed to evaluate the impact on N flows, 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, do influence the net input of N. Thereby, the net input of P and Zn is also reduced. The measures leading to reduction in life stock (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 [14] are often based on expert judgement. 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 have a feeling of what can happen when the mentioned measures are fully implemented.

Table 3. Management measures (good farming practices) and structural measures in Dutch that were evaluated with IMITATOR

Nr	Measure	Type[1)]	Explanation[2)]
1	Decrease livestock intensity	M/T	Ongoing process due to actual policy
2	Improving animal feeding	M	Enhancing the N and P efficiency in all animal categories
3	Reducing fertiliser use	M	Due to a better use of fertilisers and animal manure through precision agriculture
4	Apply cover crops	M	On arable land more N, P and Zn will be taken up.
5	Optimal drainage	M	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	M	Results in a lower NH_3 emission fraction for application and storage
7	Reduce grazing time	M	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 (AMVB)	T/M	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	T	Apply lowest NH_3 emission fractions possible for pig and poultry farms.
10	Extremely low emission housing for dairy farms	T	Apply lowest NH_3 emission fractions possible for dairy farms
11	Manure processing	T	Processing the manure surplus without any emission losses
12	Improving workability factor of animal manure	T	Increase N and P efficiency and causes a lower N and P input by fertilizer
13	Buffer strip	T	Manure and fertiliser free zones along drainage canals. Reduces runoff of N and P but increases leaching.
14	Emission free pig and poultry husbandry	T	Remaining pig and poultry are staying in NH_3 emission free stables and all manure is processed and transported (target NMP4 for 2030)

1) M: management measure; T: technical measure
2) Background information is given in [16].

RESULTS

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 4. 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. For soils, even a very small net CH_4 sequestration was calculated (-0.1 kton.yr^{-1}). Implementation of good farming 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% only (Table 4). NH_3 reductions do approach the required reductions of 100 kton.yr^{-1} for the year 2010, but not the required 50 kton.yr^{-1} for the year. A 6% reduction in N_2O emission is also attained.

Tables 4 Estimated emissions of NH_3, N_2O and CH_4 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 (GFP = Good farming practices) and technical measures (PTM= *Plus* technical measures), using IMITATOR.

System	Emissions (kton.yr^{-1})								
	NH_3			N_2O			CH_4		
	SR	GFP	PTM	SR	GFP	PTM	SR	GFP	PTM
Housing System	81	49	22	2	1.7	1.3	304	254	246
Agricultural soil	60	23	19	32	17	15	108	52	52
Total	141	72	41	34	19	16	416	306	298

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) do reduce the CH_4 emission. The reduction in emission from both the housing system and the soil is relatively larger for NH_3 than for N_2O, which is to be exopected since part of the measures (6-8) focus only on the fate of NH_3. Nevertheless, the percentage reduction is quite comparable for N_2O since most occurs in the field inresponse to N inputs, and the measures do lead a strong reuction in the net N input (Table 4). 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 5), 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 CH4 emission, but the effect is very small, since it only affects the methane emissions from stored manure (Table 6).

Element budgets for nitrogen, phosphorous and zinc

The accumulation and leaching/runoff of N, P and Zn from agricultural soils in the year 2000 and the impacts of management measures and structural measures on these element budgets are presented in Table 5. 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% for both elements for the standard run. In case of N there is a net source due to net mineralisation of peat soils [8]. The relatively low leaching and runoff is due to denitrification, being approximately 50% of the net N input.

Impacts of management measures do 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%). The release by net N mineralisation hardly changes. The reduction in denitrification is, however, only slightly higher than 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 now approximately 10% of the total input.

Table 5 Estimated element balances of N, P and Zn 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 measure (GFP = Good farming practices) and technical measures (PTM= *Plus* technical measures), using IMITATOR.

Flux type	Annual flux (kton.yr^{-1})								
	N			P			Zn		
	SR	GFP	PTM	SR	GFP	PTM	SR	GFP	PTM
Input[1]	930	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	34	7.3	4.1	0.64	0.16	0.12
Runoff	52	26	15	1.4	0.89	0.64	-	-	-
Leaching	90	31	33	17	11	11.2	0.32[2]	0.28[2]	0.28[2]

[1] In case of N, the NH_3 emission in the field (see Table 4) is already subtracted from the input.

[2] Including runoff

In case of P and Zn, the reduction in accumulation is much higher than the reduction in net input (75-80%). Consequently, the sum of the leaching to ground water and runoff to the ditches as compared the total input increases for those elements to 20% for P and 245 for Zn (Table 5). The remaining reduction in element inputs by structural 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 in the case of N (mainly because of measure 13: buffer strip) but it hardly affects the runoff and leaching of P and Zn. The reduced inputs of those elements are mainly accounted for by a redcued soil accumulation (Table 6).

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

The concentrations of nitrate (nitrogen), phosphate and zinc in soil, soil solution, ground water or surface water for the standard run and the impacts of management measures and structural measures on these concentrations are presented in Table 6. 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 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. The critical limits are hardly exceeded on clay and peat soils in the case of N and Zn, 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, irrespective of the hydrological situation.

Good farming 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 %). He reductions of P in runoff to surface water (15%) and of Zn in soil solution (7%) are comparatively low, showing that their behaviour, ben after a 30-year priod is mainly governeed by the P and Zn pool in the soil, which hardly chnage in that period (Table 6). However, the steady state Zn concentration in soil and soil solution, that is reached at an infinite time period is strongly influenced by good farming practices.

Table 6 Calculated annual average concentrations 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 after implementation of good farming practices and technical measures measures, using IMITATOR.

Scenario	$[NO_3]$ in leachate to ground water	[N] in runoff to surface water	P_{ox} in soil	[P] in runoff to surface water	Zn in soil	[Zn] in soil solution
	$(mg.l^{-1})$	$(mg .l^{-1})$	$(mmol.kg^{-1})$	$(mg .l^{-1})$	$(mg.kg^{-1})$	$(\mu g.l^{-1})$
Standard run	51	4.9	37.2	0.68	73.5	54
Good farming practices	17	2.3	37.0	0.58	69.0	48
Plus Technical measures	17	1.4	36.9	0.42	68.6	47
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 a natural background concentration in soil or surface water [13].

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 farming practices are applied. Similarly, the average value for the dissolved Zn concentration is 262 $\mu g.l^{-1}$ for the standard run and 169 $\mu g.l^{-1}$ after the application of all management measures. Technical measures mainly affect the runoff of N and P to surface water due to a buffer strip (measure 13).

DISCUSSION AND CONCLUSIONS

From this study, it can be concluded that:

- 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 farming 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 CH4 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 do only slightly affect the emissions of N_2O and CH_4

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