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Agricultural scenariosto reduce the national phosphorus surplus in the Netherlands

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Summary

The national phosphorus balance can be made more sustainable by reducing the accumulation of phosphorus in agricultural soils and by increasing recycling from waste streams. In this study we investigated different scenarios for reduction of the national soil surplus on agricultural land. The focus was on scenarios that will not compel agriculture in the Netherlands to change radically *e.g.* reduction of phosphorus fertilisation levels and reducing animal phosphorus excretion by improving feeding efficiency while maintaining national milk and meat production levels.

The national phosphorus flows in 2008 were taken as the reference situation. For this purpose the earlier assessed flow scheme of 2005 was updated. The 2008 flow scheme includes the initial years after introduction of new mineral legislation in 2006 that is based on maximum allowed application standards for nitrogen and phosphorus instead of maximum allowed surpluses (Minas).

Differences phosphorus flows 2005 and 2008.
The national phosphorus surplus in 2008 decreased by 9 Mkg P in comparison to 2005 (values for 2005 and 2008 were 60 and 51 Mkg P, respectively) (Table S1). This was mainly due to a reduction in use of mineral fertilisers (9 Mkg P), an increased manure export (6 Mkg P) alongside a net import increase of the industry (6 Mkg P). The latter was due to an increase in feed phosphorus import while the net food phosphorus import decreased. The decrease in the use of mineral phosphorus fertilisers will probably be due to the change in legislation in 2006 as from that year mineral phosphorus fertilisers were included.

The phosphorus surplus is accumulated on agricultural land, sequestered in waste and leached to ground and surface water. Phosphorus accumulation on agricultural land decreased by 12 Mkg P (values for 2005 and 2008 were 31 and 19 Mkg P, respectively). This reduction was mainly on grassland and maize fields. The phosphorus sequestered in waste increased by 3 Mkg P (values for 2005 and 2008 were 21 and 25 Mkg P, respectively). The amount of phosphorus leaching to ground and surface water decreased slightly mainly due to cleaner effluent from wastewater treatment plants (values for 2005 and 2008 were 7 and 6 Mkg P, respectively).

Table S1. **National phosphorus budget in 2005 and 2006 in the Netherlands (Mkg P/a).**

	Subsystem	Products	2005	2008
Import	Agriculture	Fertiliser	21.0	12.0
		Living animals[1]	0.2	0.2
	Industry	Feed	50.4	60.1
		Food	28.0	31.1
		Non-food	1.4	3.3
		Feed additives	7.2	8.1
	Total import		108.2	114.8
Export	Agriculture	Manure	7.0	12.8
	Industry	Food	37.5	47.6
		Non-Food	1.3	1.2
	Waste	Waste	2.7	2.0
	Total export		48.5	63.6
Surplus			59.7	51.2

1 veal production

Scenarios to reduce the national phosphorus surplus

Phosphorus Application standards 2013 en 2015
The legislation with regard to the Nitrate Directive (fourth and fifth Nitrate Action Program) contains application standards for nitrogen and phosphorus. The application standard gives the maximum allowed fertilisation level with manure and mineral fertilisers. Reduction of the phosphorus application standards to guideline levels for 2013 and 2015 will decrease the phosphorus surplus on agricultural land from 22 Mkg P in 2008 to 13 Mkg P in 2013 and 10 Mkg P in 2015 (Table S2). For grassland and maize these surpluses are 8 (2013) and 7 Mkg P (2015), for arable land 5 (2013) and 3 Mkg P (2015). In the calculations it is assumed that for 2013 and 2015 fertilisation levels equal the application standards.

The decrease of the application standards increases the manure surplus. This is the amount of manure phosphorus that cannot be applied on agricultural land. Besides the application standards, the manure surplus also depends on the acceptance grade of manure. The acceptance grade is defined as the percentage of the phosphorus application standard that is used for manure phosphorus. On grassland and maize and on arable land on sandy soils it is expected that manure acceptance will become 100% as the use of manure will be economically more profitable than mineral fertilisers. On arable land on clay soils, however, manure use is limited by the risks of damage to soil structure. For these reasons, an acceptance grade of 100% is not common on clay soils. Therefore, we distinguished different manure acceptance levels on arable land.
In a situation with an acceptance grade of 100% (without use of mineral phosphorus fertiliser on grassland and maize as well as arable land) the manure surplus is 10 (2013) and 13 Mkg P (2015). These values are lower (2013) or equal (2015) to the amount of manure phosphorus that is exported in 2008. With a manure acceptance grade of 80% on arable land and 100% on grassland and maize, the manure surplus increases to 14 and 16 Mkg P for 2013 and 2015, respectively.

Phosphorus mining scenarios
As the reduced phosphorus application standards in 2013 and 2015 result in a further phosphorus accumulation on agricultural land, two additional mining scenarios have been studied involving a further reduction in phosphorus fertilisation levels.

In the first scenario (Mining 1) balanced phosphorus fertilisation is applied on soils in soil test phosphorus class neutral (57% of grassland, 33% of arable land) and high (23% of grassland, 38% of arable land) while on soils in soil test phosphorus class low (20% of grassland, 29% of arable land) the application standards of 2015 are maintained. Balanced fertilisation is defined as: phosphorus input through fertilisation (animal manure, mineral fertiliser, other organic products and seed material) is equal to phosphorus removal through harvested products. For grass, maize and arable land balanced fertilisation represents 72, 62 and 56 kg P_2O_5 per ha, respectively (equivalent to 31, 27 and 24 kg P per ha). The soil test phosphorus is the amount of soil phosphorus that is available for crop uptake indicated as P-Al for grassland and Pw for arable land. The classes (low, neutral and high) refer to that used in the fourth and fifth Nitrate Action Program.
Compared to the scenario using application standards 2015, in scenario Mining 1 phosphorus surplus on agricultural land is reduced by 5 Mkg P (Table S2). However, phosphorus accumulation still occurs (5 Mkg P). This is due to the phosphorus accumulation on land in soil test phosphorus class low.

In scenario Mining 2 balanced fertilisation is applied on soils in soil test phosphorus class neutral and zero fertilisation on soils in soil phosphorus class high. As in scenario Mining 1 on soils in soil phosphorus class low, the application standards of 2015 are maintained. This scenario results in a soil phosphorus depletion of agricultural land of 10 Mkg P on a national level (Table S2).

The two mining scenarios increased the manure phosphorus surplus. For scenario Mining 1, the surplus is 21 Mkg P (manure acceptance grade of arable land 80%) and 18 Mkg (manure acceptance grade arable land 100%). For the Mining 2 scenario the surpluses are 35 Mkg P (manure acceptance arable land 80%) and 33 Mkg P (manure acceptance arable land 100%).

Table S2. **Phosphorus surplus on agricultural land and manure surplus in 2008 (reference) and for the scenarios Application Standard 2013, Application Standard 2015, Mining 1 and Mining 2 (for explanation scenarios see text).**

	Manure acceptance grade arable land[1]	2008 (ref)	Application standard 2013	Application standard 2015	Mining 1	Mining 2
Soil surplus	80	22	13	10	5	-10
(Mkg P)	100	22	13	10	5	-10
Manure surplus[2]	80	*13*[3]	14	16	21	35
(Mkg P)	100	*13*[3]	10	13	18	33

1 manure acceptance grade on grassland and maize = 100%
2 manure surplus = the amount of manure phosphorus that cannot be applied on agricultural land
3 manure export in 2008

Lower animal phosphorus excretion

Reducing the national phosphorus surplus is also possible by a reduction of feed imports. Scenarios were evaluated that reduced the feed input while maintaining the national milk and meat production. For dairy cattle as well as intensive livestock (pigs and poultry) the effects of 10% less phosphorus in concentrates were studied. Earlier studies showed that this reduction should be possible without affecting animal production. Additionally, for dairy cattle the effects of a 10% higher milk production per cow is investigated while maintaining the national milk production. This will result in a reduction of the national dairy herd. For all scenarios 2008 was taken as the reference.

Feeding concentrates containing 10% lower phosphorus for dairy cattle and intensive livestock reduces the national phosphorus surplus by 2 and 5 Mkg P, respectively (Table S3).

Increasing milk production per cow by 10% while maintaining the national milk production (*i.e.* 10% fewer cows) will not decrease the national phosphorus surplus (Table S3). The effect of fewer animals is counteracted by an increase in feed demand per cow by almost 10 % and a decrease in beef export from dairy cattle due to fewer dairy cow replacements. The higher feed demand is due to a higher energy demand that is necessary to realize the higher milk production. The extra energy demand is partly realized by a higher daily feed intake. However, as the maximum intake is limited by the size of the rumen, also the ratio of concentrates to roughage had to be increased to realize the higher energy demand.

In future, breeding might enhance the feeding efficiency of dairy cows. This can be due to physical changes, e.g. a larger rumen resulting in a higher maximum daily intake, or due to an increase in digestive efficiency resulting in a decreased feed demand.
In a situation that maximum daily feed intake is increased by 10% the higher milk production can be realized with the same ratio of concentrates to roughages in the ration as in the reference situation. This will reduce the national surplus by 0.2 Mkg P only.
In a situation that the digestive efficiency is increased by 10% the higher milk production can be realized with the same feed intake and the same ratio of concentrates to roughage per cow in the ration as in 2008. This results in a reduction of the national surplus by 4 Mkg P. However, this scenario demands great effort and commitment from dairy farmers and is unlikely to be achieved in the short term (*i.e.* before 2015).

Table S3. **Effects of feeding scenarios for dairy cattle and intensive livestock on change of the national phosphorus surplus (Mkg P) compared to 2008.**

	Description	Change national phosphorus surplus (Mkg P)
Dairy 1	10% less phosphorus in concentrates	-1.8
Dairy 2[1]	10% higher milk production per cow + adjusted ration	+0.3
Dairy 3[1]	10% higher milk production per cow + 10% higher daily feed uptake capacity	-0.2
Dairy 4[1]	10% higher milk production per cow + 10% higher digestive efficiency	-4.0
Intensive livestock	10% less phosphorus in concentrates	-5.0

1 national milk production level as in 2008

1 Introduction

Phosphorus flows in the Netherlands
Phosphorus (P) is an essential element to food production. This is reflected by the widespread use of phosphorus fertiliser (globally about 17Mt P per annum). The main source of phosphorus fertiliser is rock phosphate and 80% of mined phosphate is used directly for fertilisers. Rock phosphate is, however, a finite resource. Although there is a lot of uncertainty about the available deposits, it is assumed that world resources of phosphorus are relatively small. In an editorial report published in Nature (2010), it is estimated that the known deposits will be depleted within 50 to 400 years at the current rate of extraction. This wide range is due to uncertainties in the stocks of rock phosphate, especially the stocks that are more difficult to be mined.

This emphasizes the need for efficient use of phosphorus in general and particularly in agriculture. Previously, phosphorus flows in the Netherlands have been quantified (Smit *et al.*, 2010). For 2005, the phosphorus flows for the various subsystems in the national system were processed in a Material Flow Analysis (MFA), which provides a systematic assessment of the flows and stocks of materials. These subsystems are: agriculture (arable farming, grazing animals and intensive animal husbandry), industry (feed, food and non-food), households and waste disposal. The mass balance for the Netherlands in 2005 showed a large phosphorus surplus (60 Mkg P). Roughly half of this amount accumulated in agricultural soils. About 25 Mkg P was sequestered in various waste streams (landfill, incineration ashes, sewage sludge etc.) and not recycled to agriculture. The remainder was deposited in ground and surface water (7 Mkg P).

Motives and goal of the study
The national phosphorus balance can be made more sustainable by reducing the accumulation of phosphorus[1] in agricultural soils and by increasing recycling from waste streams. The major goal of this study was to investigate agricultural scenarios that reduce soil accumulation. Attention was given to scenarios that would not compel agriculture in the Netherlands to change radically e.g. reduction of phosphorus fertilisation levels and reducing the phosphorus excretion per animal by improving feeding efficiency while maintaining milk and meat production. More drastic measures such as reducing the total national animal production level by reducing animal numbers will be addressed in a subsequent study.

General description of methodology and report outline
The national phosphorus flows in 2008 were taken as the reference situation. For this purpose the phosphorus flow scheme of 2005 was updated for 2008. The 2008 flow scheme includes the initial years after introduction of new mineral legislation in 2006 that is based on maximum allowed application standards for nitrogen and phosphorus instead of maximum allowed surpluses (Minas). In Chapter 2, the changes in phosphorus flows on the national balance and for the different subsystems (agriculture, industry, households and waste) are elucidated.

Chapter 3 presents the effects of various agricultural scenarios on phosphorus accumulation in soil and changes in national phosphorus flows. Attention is given to decreased phosphorus fertilisation levels and increasing phosphorus feeding efficiency.

Reductions in fertilisation levels were performed stepwise. Firstly, fertilisation was reduced to legally proposed levels for 2013 and 2015 as described in the Fourth and Fifth Nitrate Action Programme (Anonymous, 2009). In addition to the 2015-scenario a zero scenario was considered in which no mineral phosphorus fertiliser (only organic fertilisers) and a 'mining' scenario involving

[1] In this report, phosphorus flows are expressed as kg elemental P. In agriculture, however, phosphorus is expressed as phosphate (P_2O_5); *i.e.* 1 kg P = 2.29 kg P_2O_5 and
1kg P_2O_5 = 0.44 kg P.

phosphorus fertilisation levels that are equal or lower than phosphorus removal by crops on soils with a high phosphorus content (soil phosphorus depletion).

Phosphorus excretion by intensive and extensive (grazing) livestock can be reduced by increasing phosphorus feeding efficiency. In this way meat and milk production levels are maintained with less feed phosphorus resulting in lower phosphorus excretion. This scenario was investigated for the dairy as well as the intensive livestock sector. An additional scenario was studied for the dairy sector in which the total national milk production was realised with fewer dairy cows producing more milk per cow.

Results are discussed in Chapter 4 and the conclusions are drawn in Chapter 5. At the end a short glossary is given for specific terms used in this report.

2 Phosphorus flows in 2005 and 2008

2.1 National balance

Smit *et al.* (2010) have calculated the Dutch national phosphorus flows for agricultural production, industrial processing and households for 2005. In 2006, new legislation on fertiliser use[2] was introduced containing application standards for the use of nitrogen and phosphorus from animal manure and mineral fertiliser. The national phosphorus flow scheme for 2008 included the effect of the new legislation. Figure 2.1 contains flow schemes for both years (see Appendix for more details).

The Netherlands is a net importer of phosphorus (Table 2.1). Phosphorus import was 108 Mkg P in 2005 and increased to 115 Mkg P in 2008. In the same period phosphorus export increased from 49 to 64 Mkg P. Consequently, the national phosphorus surplus decreased from 60 (2005) to 51 Mkg P (2008).

The reduction of the national phosphorus surplus was mainly due the decreased use of mineral fertilisers (-9 Mkg P) and the increased export of manure (+6 Mkg P) together with the increased net import of the industry (+6 Mkg P) altogether resulting in a reduction of the national surplus with 9 Mkg P. The increased industrial import was due to an increase of feed whereas the net phosphorus import with food decreased. Phosphorus accumulation on agricultural land decreased with 11 Mkg P while the accumulation in sequestered waste was 4 Mkg P higher.

Table 2.1 **National phosphorus budget in 2005 and 2008 in the Netherlands (Mkg P/a).**

	Subsystem	**Products**	2005	2008
Import	Agriculture	Fertiliser	21.0	12.0
		Living animals	0.21	0.22
	Industry	Feed	50.4	60.1
		Food	28.0	31.1
		Non-food	1.4	3.3
		Feed additives	7.2	8.1
	Total import		*108.2*	*114.8*
Export	Agriculture	Manure	7.0	12.8
	Industry	Food	37.5	47.6
		Non-Food	1.3	1.2
	Waste	Waste	2.7	2.0
	Total export		*48.5*	*63.6*
	Balance surplus		59.7	*51.2*

[2] Up to 2006, MINAS legislation was valid; a standardized nutrient balance sheet. Only animal manure phosphorus was accounted for, not mineral fertiliser phosphorus.

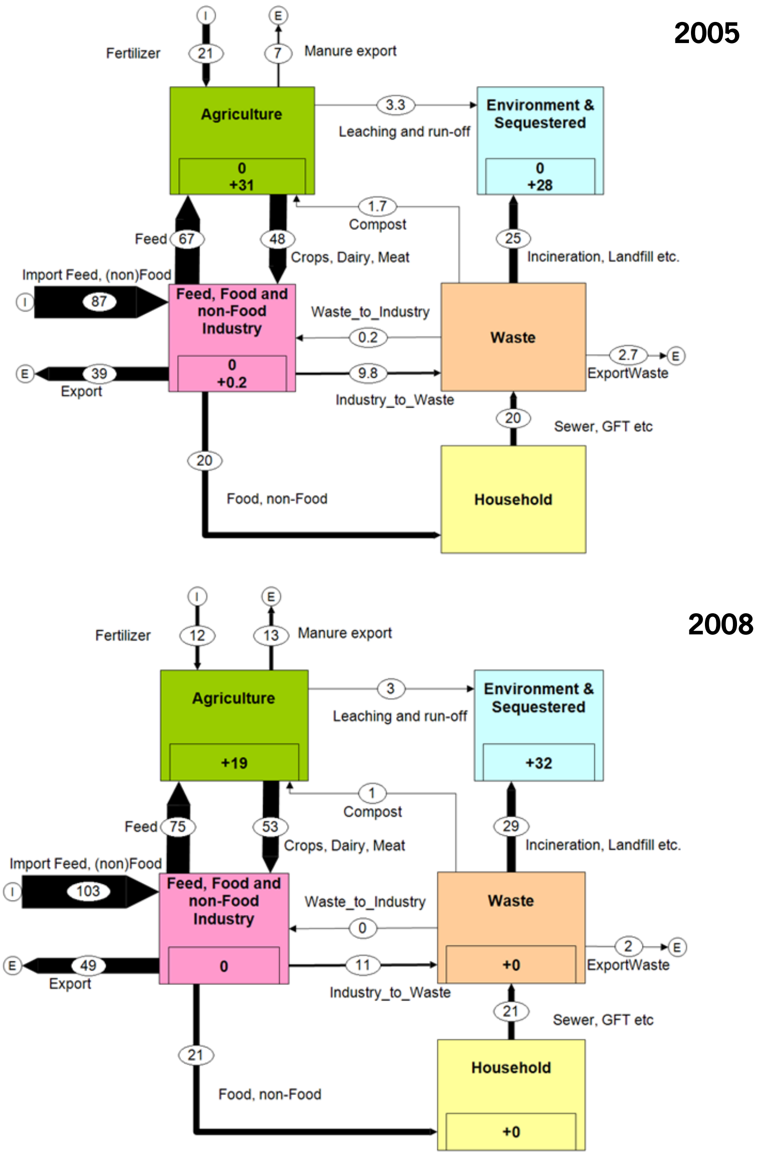

Figure 2.1 **Scheme of the national phosphorous flows (Mkg P/ha) for the main systems agriculture, industry, household, waste and environment/sequestered in 2005 and 2008.**

2.2 Arable land

Phosphorus accumulation on arable land did not change between 2005 and 2008 (Table 2.2). The phosphorus input from animal manure increased while input from all other sources decreased. The total volume of phosphorus output from arable products in 2008 was similar to 2005. It is remarkable that less feed and more food was produced in 2008 compared to 2005.

New manure legislation introduced in 2006 did not reduce phosphorus accumulation on arable land in 2008.

Table 2.2 **Phosphorus flows (Mkg P/a) on arable land in 2005 and 2008 in the Netherlands.**

	Products	2005	2008
Input	Animal manure	11.5	13.4
	Mineral Fertilisers	9.3	8.5
	Sugar factory lime	1.5	1.1
	Compost	1.0	0.8
	Sludge/waste	0.8	0.4
	Seeds/plants	0.4	0.3
	Total	*24.3*	*24.5*
Output	Crops to Food	7.7	11.4
	Crops to Feed	5.8	2.6
	Crops to Non-Food	1.3	1.1
	Leaching/Runoff loss	1.1	1.1
	Total	*16.0*	*16.3*
Accumulation		8.3	8.2
in kg P/ha		12.5	12.5

2.3 Grassland and maize

Contrary to arable land, the phosphorus accumulation on grassland and maize fields decreased (–12 Mkg P, Table 2.3). This was due to a substantial input reduction from fertiliser (–8 Mkg P) and a minor reduction of manure (–2 Mkg P). Total phosphorus output from grassland and maize was slightly higher in 2008. Hence, the decrease in phosphorus accumulation on grassland and maize is a consequence of reductions in use of manure and mineral fertilisers.

Table 2.3 **Phosphorus flows (Mkg P/a) on grassland and maize in 2005 and 2008 in the Netherlands.**

	Products	2005	2008
Input	Animal Manure	52.5	50.4
	Mineral fertilisers	11.7	3.5
	Total	*64.2*	*54.0*
Output	Crops, grass & maize	39.1	40.7
	Leaching losses	2.1	2.1
	Total	*41.2*	*42.8*
Accumulation		23.0	11.1
in kg P/ha		19	9

2.4 Grazing livestock

No significant changes were observed in the phosphorus for grazing livestock between 2005 and 2008 (Table 2.4). Total phosphorus input from feeds increased slightly (+2 Mkg P).

Table 2.4 **Phosphorus flows (Mkg P/a) in grazing livestock in 2005 and 2008 in the Netherlands.**

	Products	2005	2008
Input	Roughage, grass, maize	39.3	40.8
	Concentrates	16.9	17.7
	Rest products from food industry	2.1	2.4
	Rest	1.9	1.6
	Total	*60.3*	*62.5*
Output	For meat production	5.2	5.3
	Milk	10.8	11.6
	Pasture manure	9.3	9.4
	Manure in storage	34.6	35.9
	Dead animals	0.5	0.5
	Total	*60.3*	*62.6*
Accumulation		0.0	0.0

2.5 Intensive livestock

The intensive livestock sector was larger in 2005 than in 2008. Pig numbers increased from 20.4 M in 2005 to 23.1 M in 2008. The poultry sector grew slightly from 76.1 M to 78.2 M animals (CBS, 2007 and 2010). As a consequence, feed phosphorus input increased (+7 Mkg P) and, subsequently, phosphorus output with meat production and manure increased (+3 Mkg P and +4 Mkg P respectively) (Table 2.5).

Table 2.5 **Phosphorus flows (Mkg P/a) in intensive livestock in 2005 and 2008 in the Netherlands.**

	Products	2005	2008
Input	Concentrates	44.3	49.7
	Rest	0.1	1.8
	Total	44.4	51.6
Output	Meat production[1]	14.7	17.3
	Eggs	1.0	1.1
	Manure in storage	27.2	31.3
	Dead animals	1.5	1.8
	Total	44.4	51.6
Accumulation		0.0	0.0

1 Meat, bones and offal are included in meat production.

2.6 Industry

Total phosphorus turnover in the industry increased by approximately 20 Mkg between 2005 and 2008. (Table 2.6) This was mainly due to an increased input from meat and eggs and imports of feeds and feed additives.

Table 2.6 **Phosphorus flows (Mkg P/a) in industry in 2005 and 2008 in the Netherlands.**

	From/to subsystem	Products	2005	2008
Input	Arable farming	Food crops	7.7	11.4
		Feed crops	5.8	2.6
		Non-food crops	1.3	1.1
	Grazing livestock	Dairy and meat	16.5	17.3
	Intensive livestock	Meat and eggs	17.2	20.2
	Import	Food	28.0	31.1
		Feed & feed additives	57.6	68.2
		Non-food	1.4	3.3
	Waste		0.2	0.0
		Total	*135.7*	*155.2*
Output	Household	Food	18.5	18.3
		Non-food	1.3	3.1
	Agriculture	Feed and by-products	67.2	74.7
	Export	Food	37.5	47.6
		Feed	0.0	0.0
		Non-food	1.3	1.2
	Waste		9.8	10.4
		Total	*135.5*	*155.2*
Accumulation			0.2	0.0

2.7 Households

In 2008 the phosphorus input for households was 1.5 Mkg higher than in 2005 (Table 2.7). This was due to an increased phosphorus input from animal and non-food products while the input from vegetables decreased. In 2008, more household phosphorus went to landfill or was incinerated than in 2005.

Phosphorus levels in dishwasher detergents for 2005 were provided by Thermphos (personal communication). The 2008 volume was calculated from published data on phosphorus discharges via domestic waste water (estimates for wastewater emissions, derived from Dutch Ministry of Infrastructure and Environment; see www.emissieregistratie.nl). Therefore, the remarkable increase from household detergents could be a result of higher consumption in 2008 or underestimation in 2005.

Table 2.7 **Phosphorus flows (Mkg P/a) in households in 2005 and 2008 in the Netherlands.**

	From/to Subsystem	**Products**	2005	2008
Input	Food industry	Food (milk, eggs, meat)	11.4	12.9
		Food (vegetables)	7.1	5.3
	Non-food industry	Non-food (detergents)	1.3	3.1
		Total	*19.8*	*21.3*
Output	Waste	Sewage	12.4	11.6
	Waste	Landfill/incineration	6.2	8.7
	Waste	Compost	1.2	1.0
		Total	*19.8*	*21.3*

2.8 Waste and waste industry

In 2008 the amount of phosphorus in household and industrial wastes was higher than in 2005 (Table 2.8). In 2008 more phosphorus was sequestered in incineration plants and the cement industry (Table 2.9). Phosphorus losses to surface water were smaller due to less phosphorus in effluent from wastewater plants. Phosphorus leaching from agriculture did not change between 2005 and 2008 (emission registration; see www.emissieregistratie.nl)

In general it is concluded that the flows in agriculture and the waste sector in 2005 and 2008 did not disclose a trend for increased use of recycled material in agriculture.

Table 2.8 **Phosphorus flows (Mkg P/a) in the waste sector in 2005 and 2008 in the Netherlands.**

	From/to subsystem	Products	2005	2008
Input	Household	Sewage, compost, landfill	19.8	21.3
	Industry	Waste (from feed, food and non-food industry)	9.8	10.6
		Total	*29.6*	*31.9*
Output	Export	Exported sludge and compost	2.7	2.0
	Industry, Household	Reused in industry	0.2	0.1
	Agriculture/gardens	Compost, used in agriculture	1.8	1.3
	Environment/ Sequestered	Sewage sludge (+ incineration), landfill, cement industry, surface water	24.9	28.4
		Total	*29.6*	*31.9*

Table 2.9 **Phosphorus flows (Mkg P/a) in surface water and sequestered waste in 2005 and 2008 in the Netherlands.**

	From/to subsystem	Products	2005	2008
Input	Waste	Effluent wastewater treatment plants	3.5	3.2
	Agriculture	Leaching & Run-off	3.3	3.3
		Total to Surface water	*6.8*	*6.4*
Output	Waste	Incinerated sludge	10.4	9.7
	Waste	Input for cement industry	3.9	6.4
	Waste	To Landfill/Incineration	7.1	9.2
		Total Sequestered	*21.4*	*25.2*
		Total	*28.2*	*31.7*

3 Scenarios

3.1 Application standards 2013/15

3.1.1 Goal

Current legislation regarding the Nitrate Directive and Water Framework Directive limits nitrogen and phosphorus fertilisation on agricultural land in order to improve the quality of ground- and surface water. In this scenario we evaluate the effects of phosphorus application standards set for 2013 (Fourth Action Programme Nitrate Directive) and 2015 (Fifth Action Programme Nitrate Directive) on the phosphorus accumulation on agricultural land.

3.1.2 Description

Phosphorus application standards

Table 3.1 shows the maximum allowed phosphorus fertilisation rates (application standards) for 2013 and draft proposal values for 2015. Allowed levels depend on phosphorus fertility levels of the soil (Soil Test Phosphorus, STP) indicated as P-Al for grassland and Pw for arable land. Three STP-classes (Low, Neutral, High) have been distinguished for both grassland and arable land (including maize land). The higher the phosphorus soil fertility the lower the phosphorus application standards.

Maximum phosphorus application levels for manure and mineral fertiliser can be calculated based on the distribution of the STP classes on arable and grassland (Table 3.2).

Table 3.1. **Phosphorus application standards (kg P_2O_5/ha) for three Soil Test Phosphorus (STP) classes on grassland and arable land in 2009, 2013 and 2015, according to the Third, Fourth and Fifth Action Programme Nitrate Directive (Anonymous, 2009).**

STP class	2009 (3rd Action Program)	2013 (4th Action Program)	2015[1] (5th Action Program)
Grassland			
- Low (P-Al < 27)	100	100	100
- Neutral (27 ≤ P-Al ≤ 50)	100	95	90
- High (P-Al > 50)	100	85	80
Arable land (including maize land)			
- Low (Pw < 36)	85	85	75
- Neutral (36 ≤ Pw ≤ 55)	85	65	60
- High (Pw > 55)	85	55	50

1 draft proposal values

Table 3.2. **Distribution of Soil Test Phosphorus (STP) classes (% of total area) of grassland and arable land in the Netherlands (Anonymous, 2009).**

STP class	Grassland	Arable land
Low	20	29
Neutral	57	33
High	23	38

Scenarios

Table 3.3 contains an overview of evaluations of the various scenarios envisaged for application standards for grassland and maize and arable land. In comparison to the situation in 2008 (reference scenario 0), the phosphorus fertilisation level (organic manure + mineral fertilisers) was reduced to the maximum allowed application standards for 2013 (scenarios 1.x) and 2015 (scenarios 2.x).

Application standards for grassland and maize were lower in 2013 and 2015 than the total amount of phosphorus applied in 2008 (reference year). Initially, in order to achieve the application standards, phosphorus supply from mineral fertiliser is reduced. If this is not enough, the animal manure application rate is then reduced. Due to high costs for manure export it is a more cost effective approach to initially reduce mineral fertiliser use than reducing manure application rates. Therefore, on livestock farms, it is considered more profitable to reduce the mineral fertiliser input.

Also on arable land, the application standards for 2013 and 2015 were lower than the total phosphorus input in 2008. Although manure is not produced on arable farms it remains an economically attractive option for arable farmers. On sandy arable soils, phosphorus demand is almost completely fulfilled by manure. However, on clay soils, mineral phosphorus fertiliser is generally not fully substituted with animal manure. As autumn application of manure is no longer allowed, manure must be applied in the spring. This increases the risks of damage to soil structure especially when manure is applied under wet conditions, limiting the use of manure. In addition, spring application of manure on clay farms is preferably performed on winter wheat. However, winter wheat crop demand for phosphorus is low. This means that extra mineral phosphorus fertiliser is required for phosphorus demanding crops such as potatoes and vegetables that do not receive manure.

For these reasons, complete substitution of mineral phosphorus fertiliser with manure is not a common choice on clay arable farms. Therefore, three levels of manure acceptance (60%, 80% and 100%) have been distinguished for application on arable land in 2013 and 2015. Manure acceptance (level) is defined as the percentage of manure in the total phosphorus application rate. The percentages apply for the total arable land including sandy soils.
For the 2013 scenarios also a scenario is evaluated involving maintaining the volume of animal manure used in the reference year (2008) (scenario 1.0).

Animal manure that cannot be applied to agricultural land, is registered as export flow on the national balance. Hence, the ‘export’ represents manure phosphorus that cannot be applied in the Netherlands. Phosphorus supplied from compost, lime from the sugar (beet) industry and sewage sludge on arable land has been estimated at the 2008 level (0.4 Mkg P) for all scenarios.

Table 3.3. **The elaborated scenarios concerning application standards for grassland and maize and arable land in 2013 and 2015.**

Sector	Scenario option	Fertilisation level	Acceptance of organic P-sources	
			Manure	Other organic sources[4]
Grassland + maize	0 (ref.)	BIN/CBS 2008[1]	CBS 2008[2]	0
	1.0	Application standard 2013	CBS 2008[2]	0
	1.1	Application standard 2013	100%[3]	0
	2.1	Application standard 2015	100%[3]	0
Arable Land	0 (ref.)	BIN/CBS 2008[1]	CBS 2008[2]	CBS 2008[2]
	1.0	Application standard 2013	CBS 2008[2]	CBS 2008[2]
	1.1	Application standard 2013	100%[3]	CBS 2008[2]
	1.2	Application standard 2013	80%[3]	CBS 2008[2]
	1.3	Application standard 2013	60%[3]	CBS 2008[2]
	2.1	Application standard 2015	100%[3]	CBS 2008[2]
	2.2	Application standard 2015	80%[3]	CBS 2008[2]
	2.3	Application standard 2015	60%[3]	CBS 2008[2]

1 Fertilisation level in 2008, according to BIN and CBS (2009)
2 Fertilisation with manure from organic sources in 2008, according to BIN and CBS (2009)
3 Level of acceptance of phosphorus in animal manure as a percentage of total phosphorus fertilisation level
4 Fertilisation with compost, spent lime from sugar beet industry and sewage sludge

Output harvested product.
Agricultural soils in the Netherlands are characterized by a high phosphorus soil fertility level (Table 3.2). In this situation, reductions in phosphorus fertilisation will not lead to decreases in yield in the short term. However, phosphorus content in harvested products may decrease. Ehlert *et al.* (2009) found that phosphorus removal by arable crops could only be explained for 46% by soil fertility level, phosphorus fertilisation, nitrogen fertilisation and soil type. Other factors appear to have a larger effect on phosphorus removal. STP level was more responsible for the variation than phosphorus fertilisation. A significant effect of phosphorus fertilisation on phosphorus removal was only observed for starch potatoes, sugar beet and winter barley. Based on the observed relationships in these three crops, a reduction in fertilisation of 25 kg P_2O_5 per ha (difference between application standards 2009 and 2015) will lead to a reduction in phosphorus removal of 2.6, 1.7 and 0.6 kg P_2O_5 per ha (equivalent to 1.2, 0.8 and 0.3 kg P per ha). Considering the acreages of these crops in 2008, this would lead to a reduction of 0.14 M kg P, which corresponds to 1% of total phosphorus output through harvested crops in 2005 and 2008. Therefore, in this study, phosphorus removal by arable crops is assumed to be constant.

It is not expected that dry matter yield on grassland will be significantly affected by a reduction of phosphorus fertilisation according to the application standards for 2013 and 2015. However, phosphorus content in grass will decrease, even on soils with high STP levels. Based on results from field experiments (Ehlert *et al*, 2008) we assumed that under the application standards from 2013 and 2015 the phosphorus content of grass dry matter is 10 % lower than in 2008.

3.1.3 Changes in phosphorus flows

Table 3.4 shows the phosphorus flows on agricultural land for the considered scenarios.

A reduction in the maximum application standards for phosphorus to the 2013 and 2015 levels would reduce phosphorus surplus on agricultural land from 22 Mkg P to 13 Mkg P, and 10 Mkg P in 2008, 2013 and 2015 respectively. On grassland and maize the surpluses would be 8 (2013) and 7 Mkg P (2015) and for arable land 5 (2013) and 3 Mkg P (2015).

Reductions in phosphorus surplus are due to a reductions in phosphorus supplied with manure and mineral fertiliser. On grassland and maize phosphorus input from manure would decrease from 50 Mkg P in 2008 to 47 Mkg P in 2013 and 45 Mkg P in 2015. Both scenarios no longer involve use of mineral fertiliser. On arable land the effects on manure and mineral fertiliser usage depend on the acceptance level of manure. If mineral fertiliser is no longer used (scenario 100%), phosphorus manure input for 2013 and 2015 will be even higher than in 2008. However, it would appear that an acceptance of 80% will be more realistic. In this situation, phosphorus manure levels will be slightly higher in 2013 and slightly lower in 2015 in comparison to 2008. Phosphorus import from mineral fertilisers are 4 and 3 Mkg P respectively.

When mineral phosphorus fertiliser (scenario 100%) is no longer used the required manure export is lower (2013) or unchanged (2015) in relation to 2008. A manure acceptance of 80% on arable land increases the manure export requirement to 14 and 16 Mkg P. In order to minimize the manure surplus, substitution of mineral fertiliser with manure on arable land should be maximized. In the discussion we will consider several measures to stimulate this.

Table 3.4 **Input and output flows (Mkg P) of the scenarios concerning application standards for 2013 and 2015 for grassland and maize and arable land.**

	Reference 2008	Scenarios application standards						
		2013				2015		
		1.0	1.1 100%[1]	1.2 80%[1]	1.3 60%[1]	2.1 100%[1]	2.2 80%[1]	2.3 60%[1]
Input								
Manure								
- Grassland and maize	50.4	47.0	47.0	47.0	47.0	44.6	44.6	44.6
- Arable land	13.4	13.4	17.5	14.0	10.5	15.7	12.6	9.4
Fertiliser								
- Grassland and maize	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- Arable land	8.5	4.1	0.0	3.5	7.0	0.0	3.1	6.3
Other products on arable land								
- Other organic fertilisers	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
- Seed	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
All products								
- Grassland and maize	54.0	47.0	47.0	47.0	47.0	44.6	44.6	44.6
- Arable land	24.1	19.7	19.7	19.7	19.7	17.9	17.9	17.9
- All agricultural land	78.0	66.7	66.7	66.7	66.7	62.5	62.5	62.5
Output								
Crops								
- Grassland and maize	40.7	38.7	38.7	38.7	38.7	37.3	37.3	37.3
- Arable land	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
- All crops	55.8	53.8	53.8	53.8	53.8	52.4	52.4	52.4
Manure								
- Export	12.8	14.2	10.1	13.6	17.1	12.9	16.0	19.2
Soil surplus								
Grassland and maize	13.3	8.3	8.3	8.3	8.3	7.3	7.3	7.3
Arable land	8.9	4.6	4.6	4.6	4.6	2.8	2.8	2.8
All agricultural land	22.2	12.9	12.9	12.9	12.9	10.1	10.1	10.1

1 Level of acceptance of phosphorus in animal manure as a percentage of total phosphorus fertilisation level

3.2 Mining

3.2.1 Goal

In paragraph 3.1 it was concluded that the maximum phosphorus application standards in 2013 and 2015 would still result in an accumulation of phosphorus on agricultural land. Therefore, in this scenario we evaluate a further reduction in phosphorus fertilisation towards a balanced fertilisation or even a negative phosphorus balance in order to reduce the accumulated soil phosphorus especially on phosphorus rich soils.

3.2.2 Description

In this study balanced fertilisation was defined as: phosphorus input through fertilisation (animal manure, mineral fertiliser, other organic products) is equal to phosphorus removal through harvested products. For grass, maize and arable land balanced fertilisation represents 72, 62 and 56 kg P_2O_5 per ha respectively (equivalent to 31, 27 and 24 kg P per ha). Distribution into STP classes for grassland and arable land (Table 3.2) were used to determine maximum P application levels for the total area. In the mining scenarios, 100% of the phosphorus in compost was accounted for[3].

Table 3.5 gives a description of the two evaluated mining scenarios, Table 3.6 contains the corresponding phosphorus fertilisation levels. The reference scenario is the phosphorus application standards of 2015. In scenario Mining 1, balanced fertilisation is applied on agricultural land with STP ≥ neutral. Mining 2, involves balanced fertilisation applied on soils where STP = neutral and zero fertilisation on soils where STP = high. Application standards 2015 were applied in both mining scenarios on soils where STP = low. These levels are higher than for balanced fertilisation (Table 3.6). This means that on these soils phosphorus will accumulate and STP is expected to increase gradually to the class "neutral" (except for phosphorus fixing soils, which only represent a small percentage of soils in the Netherlands). Real mining (P surplus < 0), only takes places in scenario Mining 2. However, in a situation with balanced fertilisation it is also expected that soil phosphorus status will gradually decrease due to phosphorus absorption in the soil and some leaching.

For reasons mentioned before (see 3.1.2) the acceptance of manure on arable land is set at 80 and 100%. Note that in scenario Mining 2, no phosphorus fertilisation is applied to phosphorus rich soils (STP class high). This implies that manure is no longer applied on 23% of the grassland area and 38% of the arable land area and that nitrogen and potassium have to be applied using mineral fertilisers.

Table 3.5. **The elaborated scenarios concerning phosphorus mining (STP = soil test phosphorus, AS = application standard, AP = Action Programme Nitrate Directive, B = balanced fertilisation, 0 = no phosphorus fertilisation).**

STP class	Reference (5th AP)	Mining 1	Mining 2
Low	AS 5th AP	AS 5th AP	AS 5th AP
Neutral	AS 5th AP	B	B
High	AS 5th AP	B	0

[3] Current legislation only accounts for 50% of the phosphorus content of compost for legal application standards.

Table 3.6 **Phosphorus fertilisation levels (kg P_2O_5/ha) according to the application standards for 2015 and in the scenarios concerning phosphorus mining for three Soil Test Phosphorus (STP) classes on grassland and arable land and maize.**

	2015 (5th Action Program)	Mining 1	Mining 2
Grassland			
- STP class high (P-Al > 50)	80	72	0
- STP class neutral (27 ≤ P-Al ≤ 50)	90	72	72
- STP class low (P-Al < 27)	100	100	100
- Average for total area grassland	90	78	61
Arable land (maize included)			
- STP class high (Pw > 55)	50	56	0
- STP class neutral (36 ≤ Pw ≤ 55)	60	56	56
- STP class low (Pw < 36)	75	75	75
- Average for total area arable land	61	61	40

3.2.3 Changes in phosphorus-flows

Compared to the reference scenario, in scenario Mining 1 (balanced phosphorus fertilisation on soils with neutral and high STP), the phosphorus accumulation on agricultural land was reduced by 5 Mkg P, but remains above zero (Table 3.7). This is due to the fact that on soils with low STP (29% of the arable land and 20% of the grassland area) phosphorus fertilisation level is higher than balanced fertilisation, leading to a surplus > 0. At a manure acceptance of 80% on arable land, 21 Mkg manure phosphorus cannot be applied and has to be exported. When mineral fertiliser is no longer used (manure acceptance of 100%), 18 Mkg manure phosphorus has to be exported.

In scenario Mining 2, there is a negative phosphorus surplus on agricultural land due to zero fertilisation on soils with high STP (38% of the arable land and 23% of the grassland area). As in Mining 1, the soils with low STP phosphorus supply from organic manure and mineral fertilisers is in accordance with application standards for 2015. On a national scale, scenario Mining 2 leads to a large increase in the volume of manure that has to be exported: 35 Mkg P at a manure acceptance rate of 80% in arable farming and 33 Mkg P with full acceptance.

Table 3.7 **Changes in phosphorus flows on agricultural land (Mkg P) for scenarios Mining 1 and 2 at two manure acceptance levels for arable land (80 and 100%).**

	Reference year 2008	Scenario					
		Application standards 2015		Mining 1		Mining 2	
		100%[1]	80%[1]	100%[1]	80%[1]	100%[1]	80%[1]
Input			*Basis scenario*				
Manure							
- Grassland and maize	50.4	44.6	44.6	39.6	39.6	30.3	30.3
- Arable land	13.4	15.7	12.6	15.5	12.4	9.5	7.6
Fertiliser							
- Grassland and maize	3.5	0.0	0.0	0.0	0.0	0.0	0.0
- Arable land	8.5	0.0	3.1	0.0	3.1	0.0	1.9
Other products on arable land							
- Other organic fertilisers	1.9	1.9	1.9	1.9	1.9	1.9	1.9
- Seed	0.3	0.3	0.3	0.3	0.3	0.3	0.3
All products							
- Grassland and maize	54.0	44.6	44.6	39.6	39.6	30.3	30.3
- Arable land	24.1	17.9	17.9	17.7	17.7	11.7	11.7
- All agricultural land	78.0	62.5	62.5	57.3	57.3	42.0	42.0
Output							
Crops							
- Grassland and maize	40.7	37.3	37.3	37.3	37.3	37.3	37.3
- Arable land	15.1	15.1	15.1	15.1	15.1	15.1	15.1
- All crops	55.8	52.4	52.4	52.4	52.4	52.4	52.4
Manure							
- Export	12.8	12.9	16.0	18.1	21.2	33.4	35.3
Surplus							
Grassland and maize	13.3	7.3	7.3	2.3	2.3	-7.0	-7.0
Arable land	8.9	2.8	2.8	2.6	2.6	-3.4	-3.4
All agricultural land	22.2	10.1	10.1	4.9	4.9	-10.4	-10.4

1 Level of acceptance of phosphorus in animal manure as a percentage of total phosphorus fertilisation level

3.3 Decrease phosphorus excretion livestock

3.3.1 Goal

Agricultural production systems in the Netherlands, including feed for the national livestock, dairy products, eggs, wool, meat and manure are important in the national flow of phosphorus. Manure phosphorus is a direct consequence of the difference between phosphorus in feed and phosphorus in animal products. In the Netherlands, the phosphorus intake of dairy cattle and intensive livestock is known to be higher than necessary required for animal production and health. This extra phosphorus can be seen as an insurance against phosphorus deficiency and as a consequence of cost efficiency. It is expected that a reduction in phosphorus intake can be achieved without consequences for production if done correctly (Van Krimpen *et al.*, 2010). Therefore, several livestock scenarios have been evaluated that are aimed at reducing phosphorus excretion in manure. Their effects on the phosphorus flows in the Netherlands have been quantified.

3.3.2 Description

Grazing animals

The intake of grazing animals is mainly determined by the intake of dairy cattle. Therefore, scenarios were evaluated based on reductions in phosphorus intake of dairy cattle. Phosphorus flows in 2008 (see paragraph 3.1) was considered as the reference scenario. Technically it should be relatively easy to achieve a reduction in the phosphorus content of manufactured concentrates by using ingredients containing less phosphorus. Presently, concentrate ingredients are selected on price and the protein content but not on phosphorus content. Possibly, consideration of phosphorus content as a criteria will increase concentrate price.

An alternative for reducing phosphorus intake of dairy cattle is to increase milk production per cow while maintaining the national milk production level. This will result in a reduction in the national dairy herd. Normally, a higher milk production is achieved by an increase in energy intake per cow. As feed intake per cow is physically limited by the size of the rumen, the ration must contain more energy per unit dry matter. This can be achieved by increasing the proportion of concentrates in the ration. However, in the future breeding might enhance the feeding efficiency of dairy cows. If this would be due to a physical change, e.g. a larger rumen, the result would be that the national dairy herd would increase intake and milk production per cow. The intake for all milking cows would be equal to that of 2008 but young stock would be reduced as less milking cows have to be replaced. As a consequence the total intake of the national dairy herd will decrease.
If a higher feeding efficiency would be due to an increase of digestive efficiency of gastro-intestinal tract, the result would be that the national dairy herd as a whole would become more efficient, producing the same amount of milk with a ration per cow similar to 2008 and for both the total herd of milking cows and the young stock a smaller intake.

The consequences of a decreased phosphorus feed intake of dairy cattle were defined as 4 scenario's: one focusing on a decreased phosphorus content in feeds and three scenarios focusing on an increased milk production.

Scenario Dairy 1: 10 % less phosphorus in concentrates

It is assumed that the phosphorus content of concentrates can be reduced by 10%. This is to be realized by the use of ingredients with a lower phosphorus content. All these ingredients will be imported (100%) and the use of domestic arable products (e.g. cereals) for feed production will be unchanged. Therefore, the phosphorus imported with feeds will decrease by 10%. Lower phosphorus intake results in a lower phosphorus production in manure.

Scenario Dairy 2: 10% more milk per cow
The milk production per cow is increased by 10 % (8000 to 8800 kg milk) by changing the ration without changing the efficiency of the cattle. Maintenance of the national milk production level requires a 10% reduction in the national herd. The number of young stock per cow and the number of calves born per cow is equivalent to 2008 levels. In the Netherlands, calves not used for replacing milking cows, are used for veal production, together with imported calves. In this scenario it is assumed that veal production is maintained at the 2008 level and that more calves are imported.
A lower number of milking cows causes a reduction in beef production. It is assumed that domestic consumption of beef will not change and that beef export will decrease.
An adjustment will have to be made to the dairy ration in order to realize the increase in milk production. The necessary adjustment to the ration has been calculated using the dairy farm model "Dairy wise" (Schils *et al,* 2007). As certain milk productions can be achieved with different rations, calculations were based on total forage maize production in 2008 and an increased use of concentrates of 50 kg per 100 kg extra milk production. Consequently, the model predicted a decrease in grass intake compared to reference levels.

This decrease of grass intake predicted in scenario Dairy 2 would imply a grass surplus. Therefore, it is assumed that the "excess" area is converted to grain production (e.g. wheat). Assuming the same production level for wheat as on arable land (31 kg P per ha, excluding straw), the national wheat import is reduced by a similar amount as produced on the replaced grassland.

Scenario Dairy 3: 10% more milk per cow + increase in feeding efficiency
This scenario (and scenario 4) is based on an increase in feeding efficiency of the dairy herd. The numbers of grazing animals per category are the same as in Dairy 2. Compared to Dairy 2, dry matter intake per cow is the same, but due to a higher feeding efficiency the ratio of concentrates to roughage (maize + grass) is lower (level 2008). This could be a achieved by breeding cows with bigger rumen.
The total amount of forage maize is the same as in 2008. Roughage intake is higher than with scenario Dairy 2. Therefore, less grassland needs to be converted to wheat production than in scenario Dairy 2.

Scenario Dairy 4: 10% more milk per cow + further increase in feeding efficiency
A further increase in feeding efficiency is assumed here implying that dry matter intake per cow and the ratio of concentrates to roughages is similar to 2008. Therefore, without changing the ration (as necessary in Dairy 2 and 3) the same milk production is realised with 10% fewer cows than in 2008. This could be achieved by increase of digestive efficiency of gastro-intestinal tract
As in scenarios Dairy 2 and 3 the total amount of maize used for roughage is kept at the 2008 level and the excess grass area is converted to wheat production.

The differences between rations for the scenarios are graphically presented in figure 3.1.

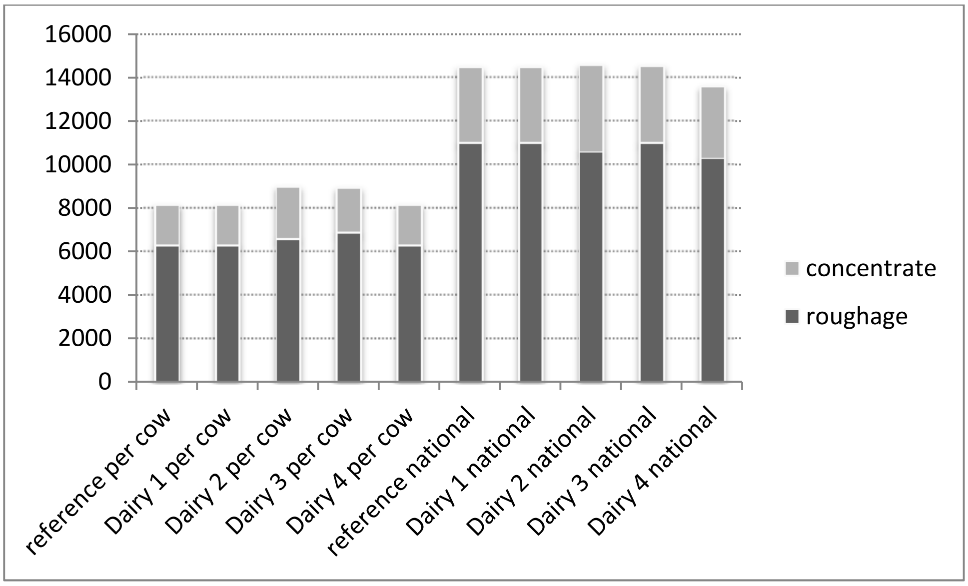

Figure 3.1 **Amount of concentrates and roughage in dairy cattle ration in reference and scenarios Dairy 1 to 4 (per cow in kg dry matter, national in Mkg dry matter).**

Scenario Intensive livestock: low-phosphorus feed
The phosphorus intake of intensive livestock originates from additives and from concentrate raw materials. Earlier studies anticipated a reduction in phosphorus intake of intensive livestock in The Netherlands without production loss of meat and eggs (Krimpen *et al.*, 2010). This scenario estimates the consequences of a 10 % decrease in feed phosphorus while maintaining production levels. It is assumed that phosphorus imports decrease, by 50 % for additives and 50 % by using ingredients lower in phosphorus.

3.3.3 Changes in phosphorus flows

Grazing animals
Results from the scenarios are presented in Table 3.8.

In *scenario Dairy 1* (10% less phosphorus in concentrates) the import, manure production and the national surplus are reduced by 1.8 Mkg P. This provides a direct reduction of soil accumulation on agricultural land, provided fertiliser imports and manure exports do not change.

For *scenario Dairy 2* (10% higher milk production) the feed intake (ration with roughages and concentrates) required is calculated using the Dairy wise farm model. In order to assess whether or not this model is suitable for use for the national dairy herd, a comparative calculation was made based on the national ration and milk production for dairy cattle in 2008 (reference). Milk production, manufactured concentrates and ratio grass: forage maize are all inputs to the model based on the national statistics. Results of the calculations predicted by the Dairy wise model correspond closely to the 2008 national ration.

Results from scenario Dairy 2 show that increasing the milk production per cow is not beneficial to the Netherlands because the national phosphorus surplus increases by 0.3 Mkg P. This is due to a small increase in imported feeds (+0.1 Mkg P) and a small decrease in exported beef (-0.2 Mkg P). The predicted increase in import of calves is negligible (0.02 Mkg P).

Despite the reduction in numbers of animals, input of phosphorus from concentrates increased by 1.9 Mkg P. If roughage phosphorus input decreases by 2.1 Mkg P, total phosphorus input from feeds will decrease slightly by 0.2 Mkg P. If meat production decreases by 0.2 Mkg P, manure production will be maintained at the 2008 level.

Increases in concentrate input have a minor effect on the total national import of feeds when grassland is partly replaced by wheat. When this extra wheat production (1.8 Mkg P) is used as a concentrate ingredient it almost compensates for the extra concentrate requirement (1.9 Mkg P).

Scenario Dairy 3 results in a small net decrease of the national phosphorus balance (-0.2 Mkg P). This is due to a decrease in feed imports (-0.4 Mkg P) together with a decrease in beef exports (-0.2 Mkg P). Similar to scenario Dairy 2, the estimated increase in calf imports remains negligible (+0.02 Mkg P).
The calculations show that phosphorus intake from feed concentrates and roughages decrease by 0.1 and 0.3 Mkg P respectively. When meat production decreases by 0.2 Mkg P, consequently manure phosphorus production will decrease by 0.2 Mkg P.

Scenario Dairy 4 leads to a reduction in the national phosphorus surplus by 4.0 Mkg P. This is mainly due to reductions in feed imports.
Use of feed concentrates and roughages decreases by 1.3 Mkg P and 3.3 Mkg P respectively. Combined with a reduction in meat production (-0.2 Mkg P) this results in a decrease in manure production of 4.4 Mkg P.

Table 3.8. **Effects of dairy scenarios 1-4 on national phosphorus flows compared with 2008.**

Per annum	2008 (reference)	Dairy 1[1]	Dairy 2[1]	Dairy 3[1]	Dairy 4[1]
Transition grassland to wheat, mln ha	0	0	0.0598	0.0088	0.0940
Import feed grazing animals, Mkg P	60.1	-1.8	0.1	-0.4	-4.2
Import calves, Mkg P	0.20	0	+0.02	+0.02	+0.02
Production wheat on former grassland, Mkg P	0	0	1.8	0.3	2.9
Production concentrates grazing animals, Mkg P	17.8	-1.8	+1.9	-0.1	-1.3
Intake roughage, Mkg P	40.7	0	-2.1	-0.3	-3.3
meat production grazing animals, Mkg P	5.3	0	-0.2	-0.2	-0.2
milk production, Mkg P	11.6	0	0	0	0
manure production grazing animals, Mkg P	45.3	-1.8	+0.05	-0.2	-4.4
National balance, Mkg P	51	-1.8	+0.3	-0.2	-4.0

1 Dairy 1: 10 % decrease of phosphorus in dairy cattle concentrates
Dairy 2: 10 % increase in milk production per cow, ration: dairy wise model
Dairy 3:10 % increase in milk production per cow, 10% higher uptake per animal, ratio of feedstuffs in ration as in 2008
Dairy 4: 10 % increase in milk production per cow, uptake per animal and ratio of feedstuffs as in 2008

Intensive livestock

Results estimated for the intensive livestock scenario are presented in Table 3.9. A 10% reduction in concentrate phosphorus for all intensive livestock reduces phosphorus excretion in manure and the national phosphorus surplus by 5 Mkg P.

Table 3.9. **Effects of decreasing phosphorus content concentrates for all intensive livestock with 10% on the national phosphorus flows compared with 2008.**

Per annum	2008 (reference)	Change in scenario Intensive livestock
Import feed intensive livestock, Mkg P	60.1	-2.5
Import feed additives, Mkg	8.1	-2.5
Produce concentrates intensive livestock, Mkg P	50.0	-5.0
Production manure intensive livestock, Mkg P	31.3	-5.0
National balance, Mkg P	51	-5.0

4 Discussion

The national picture
This study indicates that in order to halt the accumulation of soil phosphorus on agricultural land more severe application standards are required than those suggested in the 4^{th} and 5^{th} Nitrate Action Programme. This will increase the manure surplus; the amount of manure phosphorus that cannot be applied to agricultural land within the application standards. Calculations showed that balanced fertilisation of agricultural land classified with a neutral or high STP increases the manure surplus from 13-16 Mkg P (5^{th} Action Programme) to 18-21 Mkg P (depending on the acceptance grade of manure).

Proposed solutions include an initial reduction of mineral fertiliser use, but even when no mineral fertiliser is applied this has only a limited effect on the manure surplus (-3 Mkg P). Further measures to be considered, include a reduction of imports (mainly feed) or an increase in exports of phosphorus-containing products (including manure). Meanwhile the Dutch farmers association and the feed industry agreed a covenant that the phosphorus content of concentrates will be decreased with 10%.

The consequences of reducing feed imports while at the same time maintaining intensive agriculture in the Netherlands (in terms of area and number of animals) implies that more efficient production methods have to be developed, especially in the livestock industry. Calculations in this study showed that a 10% reduction in concentrate phosphorus content reduced phosphorus excretion by 2 and 5 kg Mkg P for dairy cattle and intensive livestock respectively. An alternative solution might be to increase utilization of domestic arable products for feed concentrates. This would require a substitution of cash crops such as potatoes with feed crops such as wheat. It must be emphasized that the net effect of such as measure will probably be small as in that situation the export of arable and horticultural products may decrease or the import may increase.

Improvement of sustainable phosphorus use in the Netherlands will also require a recycling of phosphorus-rich waste streams. However, such a recycling will be in direct competition with manure. Therefore, developments in recycling technologies should be aimed at export. This will have consequences for the nature of the recycling products, *e.g.* transport costs must be limited (high phosphorus concentrations and/or dry matter content), and the product must be capable of competing with mineral fertiliser (price, quality).

Phosphorus flows in 2005 and 2008.
In comparison to 2005, the national phosphorus surplus in 2008 decreased by 9 Mkg P. Phosphorus accumulation on agricultural land decreased by 12 Mkg P while the phosphorus sequestered in waste increased by 3 Mkg P. The reduction in accumulation on agricultural land was completely assigned to grassland and maize. No changes were observed in soil phosphorus accumulation on arable land. New manure legislation introduced in 2006 will have played a role. Prior to 2006, use of mineral phosphorus fertilisers was not restricted by legislation. From 2006 onwards, mineral phosphorus fertilisers have been included in legislation. Farmers have substituted the use of mineral phosphorus fertilisers for manure in an attempt to reduce manure export costs. In addition, compared to mineral legislation prior to 2006 (Minas) the application standards system allows less manure to be applied. This may be responsible for the reduction in manure usage on grass and maize land. On arable land the legal application standards for manure phosphorus did not change between 2005 and 2008 despite the change in legislation.

Manure acceptance on arable land
In order to decrease the manure surplus it is important to increase manure application for arable farms on clay soils. As mentioned previously, on clay soils in general, mineral phosphorus fertilisers is not fully replaced by animal manure. This is due to the risk of damage to soil structure when manure is applied in the spring under wet conditions. Solutions to increasing manure acceptance can be found in improved

application techniques and manure processing, providing manure products that can be more easily applied on clay soils than unprocessed manure.

Application technique
At the moment, spring application of manure on clay farms is commonly done in winter wheat. From the point of view of phosphorus demand it is preferable to apply manure in advance of phosphorus demanding crops such as potatoes and vegetables. Present research is investigating manure application techniques for potatoes but these new techniques are not yet ready for use in practice (Huijsmans & Hol, 2011).

Improved placement of mineral phosphorus fertilisers can also contribute to increased manure acceptance. Band application within the crop rows will enable a reduction in the mineral phosphorus rate and can leave more room for manure phosphorus. Recent developments are also considering band application of manure. This is currently being examined on a modest scale in maize. The maize crop reacts positively to improvements in the placement of phosphorus fertiliser (Bussink *et al.* 2011). Therefore, a starter row application of 20-30 kg P_2O_5 fertiliser per ha is very common in practice. Band application of manure will save mineral phosphorus fertiliser and reduce the risk of yield loss if starter phosphorus with mineral fertiliser is no longer applied. Using GPS controlled systems enables row application of animal manure prior to planting, improving system flexibility (Van der Schans *et al.*, 2011).

Manure processing
In addition to more advanced application equipment, processing manure is another option for increasing manure application on arable farms on clay. Different techniques are available for separation of manure into liquid and solid fractions (www.mestverwerken.nl). Most of the phosphorus is present in the solid fraction. This lighter, separated product can be applied more easily in the spring than unprocessed manure. Due to the lower N:P ratio the solid fraction is also more suitable for application in late summer in combination with a green manure crop.
Furthermore, the solid fraction, especially when dried, is more suitable for export than unprocessed manure. As the results showed, even when manure acceptance is 100%, a significant amount of manure phosphorus will have to be exported (16 Mkg P at 2015 application standards).

Application of the liquid fraction on clay soils will provide similar problems as unprocessed manure. However, use of the liquid fraction with low phosphorus content instead of unprocessed manure better suits the low phosphorus demand of winter wheat.

Digestion of manure in bio reactors is an alternative source of energy (heat and methane gas). When industrial waste flows are used as co-fermentation products, the phosphorus content increases further. This can be seen as a type of recycling of phosphorus in these waste flows. When crops or crop by-products (*e.g.* (energy-)maize, beet leaves, straw) are used for co-fermentation this does not increase the phosphorus supply to agricultural land, as in most cases the phosphorus contained in these products are returned to agricultural land (via manure or crop residues). However, when co-fermentation products are used from other sources than agriculture (e.g. industrial wastes), the phosphorus input to agricultural land increases. This extra phosphorus will compete with phosphorus from unprocessed manure and mineral fertilisers.

Manure phosphorus surplus
According to our calculations, when the application standards are reduced to levels for 2015, manure phosphorus surplus increased to 13-19 Mkg P depending on the acceptance grade of manure. Manure surplus is defined as the amount of phosphorus that cannot be applied on agricultural land and should be used outside agriculture or exported. Luesink *et al.* (2008) estimated a manure phosphorus surplus of 18 Mkg P for 2015. This corresponds favourably with our scenario with a manure acceptance grade of 60% on arable land and 100% on grassland and maize (85% on total agricultural land). An acceptance grade of 60% on arable land is quite low but it may be that the assumption of an acceptance grade of 100% on grassland and maize is too high. Possibly the phosphorus application rate on grassland and maize land is below the maximum allowed application standards. Especially on dairy farms without derogation (maximum manure

nitrogen rate standards of 170 instead of 250 kg N per ha) the nitrogen content limits the application standards of bovine manure and not the phosphorus content.

Reduced P excretion by animals
In this study scenarios involving a 10% reduction in concentrate phosphorus content for dairy cattle and intensive livestock were evaluated. According to a desk study this will not reduce animal production on dairy or intensive livestock farms (Van Krimpen *et al,* 2010). Reduction of phosphorus in concentrates should be possible without great extensive technical effort. The production process of concentrates can remain the same, only at the selection of raw materials phosphorus content should be taken into account. This has not yet been implemented in the Netherlands due to expected higher costs and risk management by farmer and feed industry. Dairy cattle are fed (more than) enough phosphorus to prevent any risk of phosphorus deficiency. At present the feed industry is working on phosphorus reduction in concentrates for dairy cattle and intensive livestock. Dutch agricultural farmers organization (LTO) and associated feed industry (NEVEDI) have agreed on a reduction in concentrate phosphorus content of 10 % in 2015. This has been estimated using scenarios “Dairy 1” and “intensive livestock” and should provide a substantial decrease in the national phosphorus balance by 7 Mkg P. It is, however, discussed whether this will decrease the soil accumulation on agricultural land or decrease the manure export. If phosphorus application standards on agricultural land are maintained, farmers can choose to increase manure rates or to use mineral phosphorus fertiliser to fulfil the application standards. In that situation not the soil phosphorus accumulation, but the manure phosphorus export will decrease. If farmers do not increase manure rates (lower phosphorus supply with manure) or increase the phosphorus mineral fertiliser rates, the phosphorus accumulation in soil will reduce. The expectation is that arable farmers will use more manure with lower phosphorus content and dairy farmers will not use more manure. In the Netherlands there is also an application standard for nitrogen from animal manure. It is expected that dairy farmers will meet this nitrogen standard and therefore will be restricted in using more manure with lower phosphorus content.

In addition to a lower phosphorus feed content, scenarios were also studied focusing on a 10% increase in milk production while maintaining the national milk production level. This implies 10% reduction in the national herd. Estimates show that positive effects on the national phosphorus surplus can only be expected together with improvements to feeding efficiency thus that minor or no ration changes per animal are necessary. According to national statistics from the last 30 years of the 20th century, average milk production per cow in the Netherlands has increased by approximately 100 kg milk per cow per year. However, more recent statistics have not indicated any further increase. Therefore, increases in milk production without substantial ration changes requires greater effort from dairy farmers (*i.e.* better stockmanship). It is considered unlikely that this can be achieved in the next 5 to 10 years.

5 Conclusions

Phosphorus flows in 2005 and 2008.

- In comparison to 2005, the national phosphorus surplus in 2008 decreased by 9 Mkg P. This was mainly due to a reduction in mineral fertiliser use (9 Mkg P) and increases in manure exports (6 Mkg P) while the net import for the industry increased (6 Mkg P). The latter was due to an increased feed phosphorus import feed while food phosphorus imports decreased.
- Phosphorus accumulation on agricultural land decreased by 12 Mkg P while the phosphorus sequestered in waste increased by 3 Mkg P. Reductions in the accumulation on agricultural land could be completely assigned to grassland and maize. No changes in soil phosphorus accumulation were observed on arable land.

Scenarios to reduce the national phosphorus surplus

Phosphorus Application standards 2013 and 2015

- Reduction of the phosphorus application standards anticipated for 2013 and 2015 will decrease the phosphorus surplus on agricultural land from 22 Mkg P (2008) to 13 Mkg P (2013) and 10 Mkg P (2015). For grassland and maize these surpluses become 8 (2013) and 7 Mkg P (2015), for arable land 5 (2013) and 3 Mkg P (2015).
- When mineral phosphorus fertiliser is not used (scenario 100% manure acceptance on arable land) the required manure export is lower (2013) or equal to (2015) that of 2008. When manure acceptance is 80% on arable land the required manure export increases to 14 (2013) and 16 Mkg P (2015).

Phosphorus mining scenarios

- Since reduced phosphorus application standards for 2013 and 2015 result in an accumulation of phosphorus on agricultural land, additional mining scenarios were evaluated. Phosphorus fertilisation is reduced further towards balanced fertilisation or soil phosphorus depletion (negative phosphorus balance) in order to reduce the phosphorus soil stock especially on soils with a high STP class (Soil Test Phosphorus).
- Compared to the scenario using 2015 application standards, in scenario Mining 1 (balanced phosphorus fertilisation on soils with STP class neutral or high), the phosphorus accumulation on agricultural land is reduced by 5 Mkg P, but remains above zero (5 Mkg P). In scenario Mining 2 (balanced fertlisation on soils with STP class neutral and zero fertilisation on class high), the phosphorus accumulation in agricultural soils is negative (-10 Mkg P).
- At a manure acceptance of 80% on arable land, 21 Mkg manure phosphorus cannot be applied and has to be exported. When mineral fertiliser is not used (manure acceptance 100%), 18 Mkg manure phosphorus has to be exported. For scenario Mining 2 the amount of manure phosphorus to be exported is 35 (manure acceptance arable land 80%) and 33 Mkg P (manure acceptance arable land 100%).

Reduced animal phosphorus excretion

- Using concentrates 10% lower in phosphorus for dairy cattle and intensive livestock results in a decrease of the national phosphorus surplus of 2 and 5 Mkg P respectively.
- Increasing the milk production per cow by 10% while maintaining national milk production (10% fewer cows) does not decrease the national phosphorus surplus. The effect of fewer animals is counteracted by an increase in feed requirement per cow by almost 10 % (increased daily intake per cow and increased ratio of concentrates to roughage in the ration) and a reduction in beef exports from dairy cattle due to fewer dairy cow replacements.
- Increasing feeding efficiency to coincide with a 10% higher milk production can be achieved by an increased maximum daily intake capacity per cow (+10%) but with the same ratio of concentrates to roughage in the ration as in 2008. This reduced the national phosphorus surplus by 0.2 Mkg P.

- Increasing the digestive efficiency by 10% (increased milk production realized with same daily intake per cow and the same ratio of concentrates to roughage in the ration as in 2008) results in a reduction of the national surplus by 4 Mkg P. However this scenario demands great efforts from dairy farmers (*i.e.* improved stockmanship) and is therefore unlikely to be achieved in the short term.

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Information on the World Wide Web was retrieved from:
www.emissieregistratie.nl
www.mestverwerking.nl

Glossary

Application standard = maximum allowed phosphorus fertilisation rate (manure and mineral fertiliser) according to the Third, Fourth and (tentative) Fifth Action Programme of the Nitrate Directive.

Balanced fertilisation = phosphorus input through fertilisation (animal manure, mineral fertiliser and other organic products) is equal to phosphorus removal through harvested products.

Concentrates = manufactured feed.

Manure surplus = the amount of manure phosphorus that cannot be applied on agricultural land.

Manure acceptance grade = the percentage of the phosphorus application standard fulfilled by manure phosphorus.

Minas (Mineral Accounting System) = legislation with regard to the Nitrate Directive based on maximum allowed surplus of nitrogen and phosphorus, that was valid until 2006.

Mining = depletion of accumulated soil phosphorus realized by a negative soil balance; *i.c.* input through fertilisation is lower than phosphorus removal through harvested products.

P-Al = soil phosphorus test based on extraction with ammonium lactate-acetate (ALA) (mass ratio water/ALA = 1/20).

Pw = soil phosphorus test based on extraction with water (volume ratio soil/water=1/60).

Roughage = fresh or ensilaged forage crops (*e.g.* gras, forage maize).

Soil surplus = difference of phosphorus inputs (through animal manure, mineral fertilisers, other organic products and seed material) and outputs (through harvested products)

Soil accumulation = the phosphorus that adds up to the soil stock, calculated as the soil surplus minus leaching losses.

Soil Test Phosphorus (STP) = the amount of phosphorus that is available for crop uptake assessed by common soil tests like P-Al and Pw.

Appendix

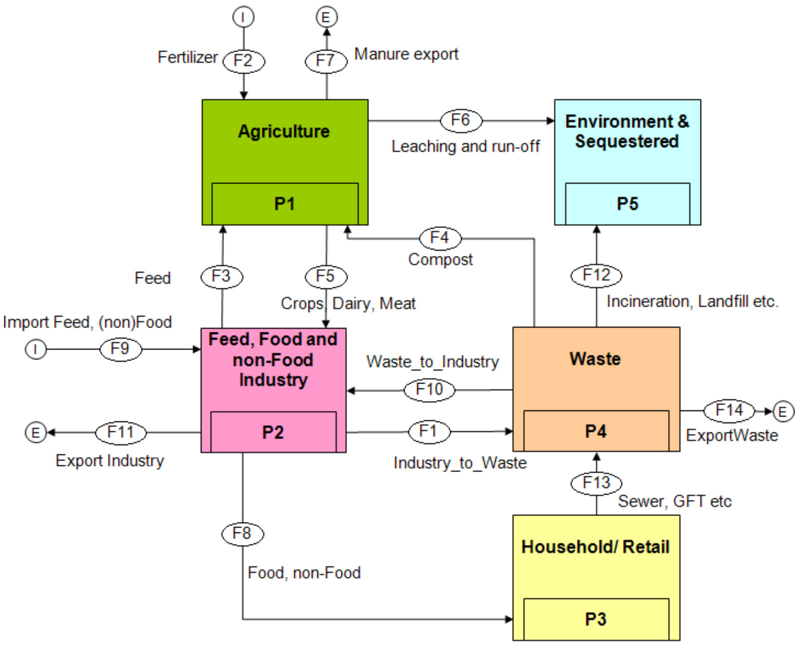

Figure A **Summarizing flow scheme for the main subsystems: Agriculture, Industry, Waste and Household/Retail.**

Table A **Description of the phosphorus flows in the summarizing flow scheme (see also Figure 2.1 for 2005 and 2008).**

Flow #	Flow Name	Description
F1	Industry_to_Waste	Waste from Food, non-Food and Feed Industry
F2	Fertilizer	Mineral P-Fertilizer used on Arable and Maize/ Grazing land
F3	Feed	Mainly feed, includes also seed & plant material and sugar beet lime from food industry
F4	Compost	Compost from household/retail to arable land
F5	Crops, Dairy, Meat	Arable crops to Food, non-Food and Feed industry; Poultry (for meat and eggs), Pigs (for meat), Grazing animals for meat, dairy products (milk), dead animals to destruction plant
F6	Leaching and run-off	From grazing, maize and arable land
F7	Manure export	Exported manure (products)
F8	Food, non-Food	Food (animal and vegetal) and non-food (*e.g.* dish washer tablets, pet food) to household/retail
F9	Import Feed, (non)Food	National import of feed (including feed additives), food and non -food
F10	Waste_to_Industry	Reuse of waste by the industry (feed)
F11	Export Industry	Food crops, non-food crops (seed potatoes and grass seeds), meat, dairy products, eggs, animals, fish, pet food and slaughter waste (bones)
F12	Incineration, Landfill etc.	Incinerated sewage sludge, (household) waste to landfills and non-intercepted P by waste water treatment plants
F13	Sewer, GFT etc	Via sewer system and with household waste
F14	ExportWaste	Exported sewage sludge