Calculation rules of the Annual Nutrient Cycling Assessment (ANCA) 2019

Background information about farm-specific environmental performance parameters

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Samenvatting NL De KringloopWijzer is een rekenmodel (software) om de gehele mineralenstroom van stikstof, fosfor en koolstof op een melkveebedrijf in beeld te brengen, alsmede een LCA analyse. De volledige rekenwijze met bijbehorende formules, coëfficiënten en standaardwaarden van de 2019-versie zijn in voorliggend rapport beschreven.

Summary UK ANCA (Annual Nutrient Cycle Assessment) is a calculation model (software) to describe the complete nutrient flow of nitrogen, phosphorus and carbon for a dairy farm, including a LCA analysis. The complete calculation method, including belonging formulas, coefficents and standard values of the 2019-version, are written down in this report

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1 Introduction

1.1 Why an Annual Nutrient Cycling Assessment?

In the pre-industrial era, crop production, processing and consumption took place in close proximity. This made it easy to reuse by-products released in the different steps. Nitrogen (N), phosphorus (P) and carbon (C) from humans and animals were locally recycled, via manure and soil, to crops, before eventually being used again by humans and animals. Along the way, N, P and C can be lost from this cycle to the environment. That happened in the past, just as it does now. Losses are partly inherent to biological processes. For example, a large part of the C ingested via feed is not stored in the animal (or in humans, or soil biota), but burned during metabolic processes in the body and converted into heat and movement, and released as carbon dioxide. When N becomes available as a fertilizer (ammonium) from dead plants and animals, it is not completely absorbed by plants. Part of the ammonium-N will be converted to nitrate-N, and eventually to elementary N. The latter form of N has no fertilizer value for most plants and as such should be considered as lost. Aforementioned losses in biological processes are only partly inevitable. Losses are also a result of the way in which people manage N, P and C flows. This is relevant because losses can have a detrimental effect on the environment. For example, losses of nitrate-N, ammonia-N and phosphate reduce the quality of ground and surface water, and losses of nitrous oxide-N, methane and carbon dioxide are greenhouse gases contributing to climate change. Initially these losses were compensated for by biological N fixation in legumes, the supply of N and P from grazing uncultivated soils, the supply of N and P by water and wind, P released by the weathering of rocks, and the ‘new’ formation of organic C through photosynthesis. Nowadays, however, farmers compensate for losses by importing synthetic fertilizers, or 'packaged' fertilizers in the form of imported feed.

Unlike in arable farms and intensive livestock farms (e.g. poultry, pigs), the local (‘short’) cycle of N, P and C via animals, manure, soil and crop is more often found on dairy farms. However, on dairy farms too, interactions with the outside world have increased, and cycles, if still existing, are often taking a longer detour. The processing of milk and meat, and housing of young stock, for example, more often takes place off-farm. In addition, the raw materials needed for animal production and for compensation of losses (fertilizers, concentrates, and other feed ingredients) are often produced off-farm. Sometimes raw materials originate from stocks built up in the past, such as fossil fuels, phosphate rock and fossil groundwater (ancient acquifers). Dairy farmers that are also keeping non ruminants[1] (e.g. poultry or pigs) or producing arable crops often have even more extensive interactions with the outside world, because of larger feed imports, more exports of excess animal manure, and/or sales of arable products.

The Annual Nutrient Cycling Assessment (ANCA; in Dutch, 'KringloopWijzer') project aims to develop, test and introduce a tool that provides a scientific, integrated, unambiguous and reliable overview of the cycle and losses of N, P and C. Previously the tool was suitable for specialized dairy farms only, but the present version of ANCA is also suitable for farms with arable production or with livestock other than dairy cows and young stock.

ANCA yields a number of key figures that agricultural entrepreneurs can use to justify their business operations to governments or processors, and to optimize their farm management. For governments, ANCA offers an opportunity to partly replace generic legislation by customization. Processors (e.g. for dairy or meat) can utilize results of ANCA to give insight in sustainability performance to consumers.

[1] Under Dutch law, the category ‘ruminants’ (‘graasdieren’) includes cattle (excluding white veal calves), sheep, goats, horses, donkeys, Mid-European red deer, fallow deer, and water buffaloes.

Mapping of N, P, and C cycles on the farm is done step by step, and ultimately leads to the following calculated key figures on an annual basis (see Figure 1.1):

1. Manure production: excretion of nitrogen (N) and phosphate (P_2O_5) by dairy cattle and associated young stock, other ruminants (breeding bulls, suckler cows, red meat bulls, rose calves, sheep, goats, horses, ponies), and non-ruminants (pigs, chickens, white veal calves);
2. Efficiency of animal feeding (i.e. conversion of feed into milk and meat): utilization of N and P_2O_5 (this calculation is limited to the dairy herd and associated young stock);
3. Emission of ammonia (NH_3) from the stable, manure storage, grazing animals, and land application of animal manure and synthetic fertilizer;
4. Yields of pasture (including goose grazing), maize silage, and other arable crops (roughage and non-roughage): dry matter, kVEM (Dutch energy unit for lactation), N and P_2O_5;
5. Fertilization efficiency (i.e. conversion of fertilizers into crop yield, including non-roughage arable crops): utilization of N and P_2O_5 present in fertilizers and animal manure (including goose excretion);
6. Soil surplus of N and P_2O_5 and the supply of effective organic matter to soils under pasture, maize silage, and any other arable crops (roughage and non-roughage);
7. Nitrate (NO_3) in groundwater; this indicator will only be shown after validation against a recent independent dataset;
8. Greenhouse gas emissions: methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2);
9. Farm surplus N, P_2O_5, and C;
10. Farm efficiency (i.e. the share of imported minerals that is converted into exported milk, meat, or non-roughage arable crops): utilization of N and P_2O_5 in purchased feed or purchased fertilizers.

The aim of this report is to describe how the above key figures are calculated and on what input data they are based. These key figures (and additional figures like 'BEX advantage', 'BEP advantage', amount of protein grown on-farm, ammonia emissions per LU, share of permanent pasture) will be reported in the the output of the ANCA tool.

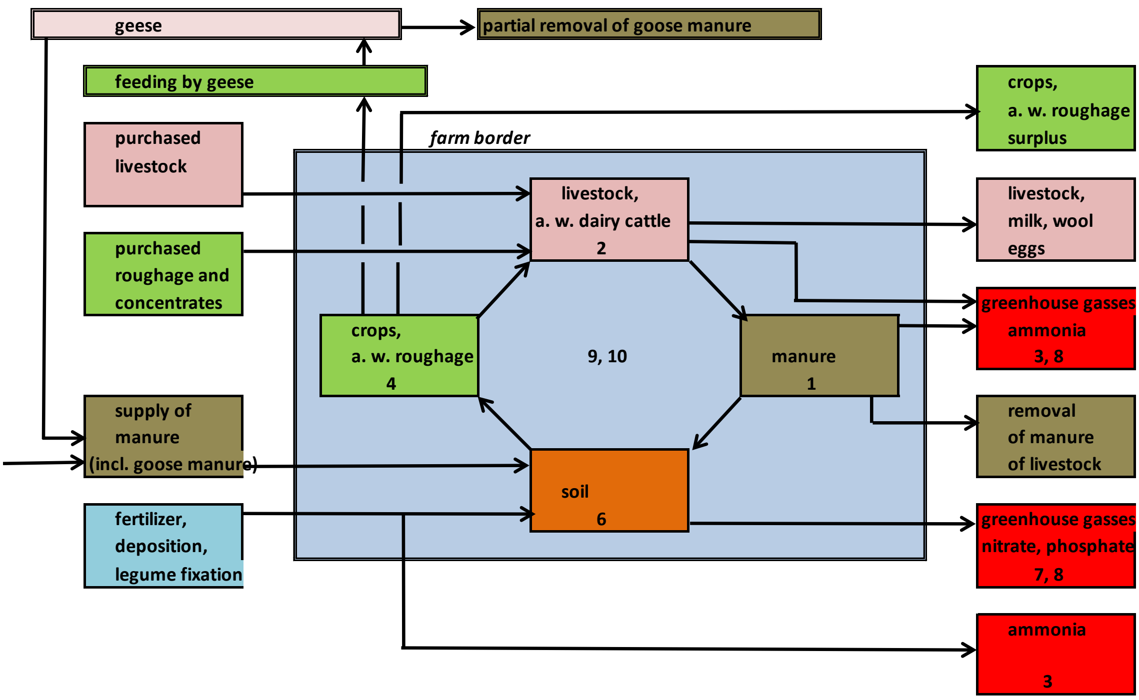

Figure 1.1 *The location of key figures (see numbers above) in the material flow through farms.*

1.2 The cycles in more detail

In order to compare the performance of farms for these indicators, agreements should be made on the method of calculation. The calculation should take into account that is much difference between farms in terms of input- and output flows. Figure 1.2 show an impression of the input and output flows on an agricultural farm. From this figure it becomes clear that the sum of N, P and C in the materials entering the farm (terms A to F) must, due to the law of conservation of mass, be equal to the sum of N, P and C in materials leaving the farm (terms G to M) and in stock changes in the farm. Many more flows can be distinguished within the company (Figure 1.3). Nutrients entering the farm enable the soil to grow crops, including: nutrient deposition, fertilizer, 'pasture manure' (manure excreted on pasture, including the excretion of geese), 'stable manure' (manure excreted in the barn, including feed leftovers), and (in some occasions) organic N fixation and mineralizing peat. The growth of crops leads to both a harvestable product and a part that is not harvested in the form of roots and stubble, which die and decompose in the soil, and thus return as nutrients to the soil. Also, not all of the harvestable part of the product is actually harvested (or during grazing, ingested), because unavoidable mowing, harvesting and grazing losses. These losses, similar to roots and stubbles, largely return to the soil. Even after the harvested product leaves the field, not all will be ingested by the cattle, since part will be lost during the storage and conservation of feed, and losses will also occur between feeding out the silage and ingestion, the so-called feed losses. Table 1.1 gives an overview of the various loss percentages that are currently being used in the ANCA tool. These differ per product and, within a product, per substance. In reality, these losses have no fixed value and will vary as a result of, inter alia, management. However, it is impossible to specify the values per farm in a simple and reliable manner.

Table 1.1 *Percentages of field loss, conservation loss, and feed loss used in the ANCA tool.*

	Field loss	Conservation loss				Feed loss
	DM, NEL[1], N, P	DM	NE	N	P	DM, NE, N, P
Pasture grass, limited grazing	15	0	0	0	0	0
Pasture grass, unlimited grazing	20	0	0	0	0	0
Pasture grass, summer stall-feeding	5	0	0	0	0	0
Cut grass for ensiling	5	10	15	3	0	5
Maize silage	2	4	4	1	0	5
Other home-grown roughage	2	4	6	1.5	0	3
(supplied) wet by-products	0*	4	6	1.5	0	3
Single concentrate feed	0*	4	6	1.5	0	2
Compound concentrate feed and milk products	0*	0	0	0	0	2
Minerals (salts)	0*	0	0	0	0	2

* Field losses may be present, but take place off-farm.

[1] Net Energy Lactation

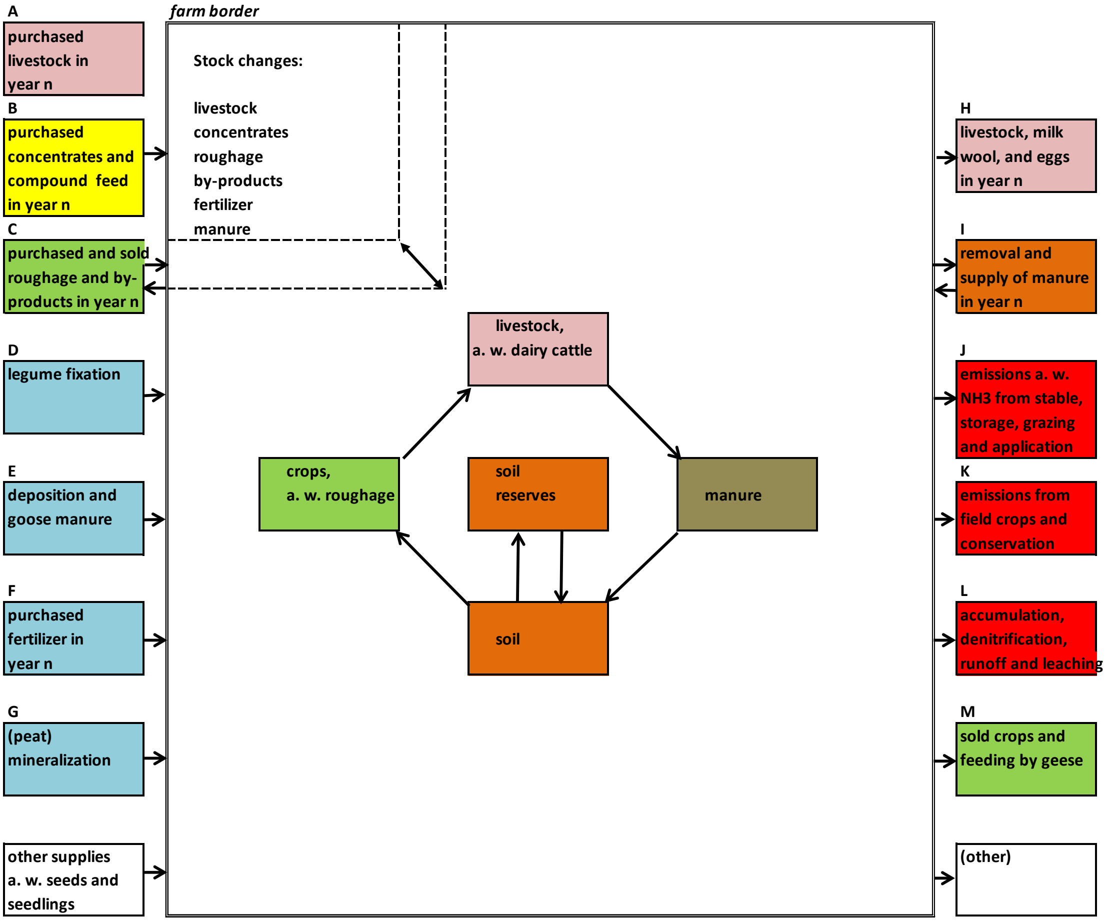

Figure 1.2 *Material input and output flows on a farm.*

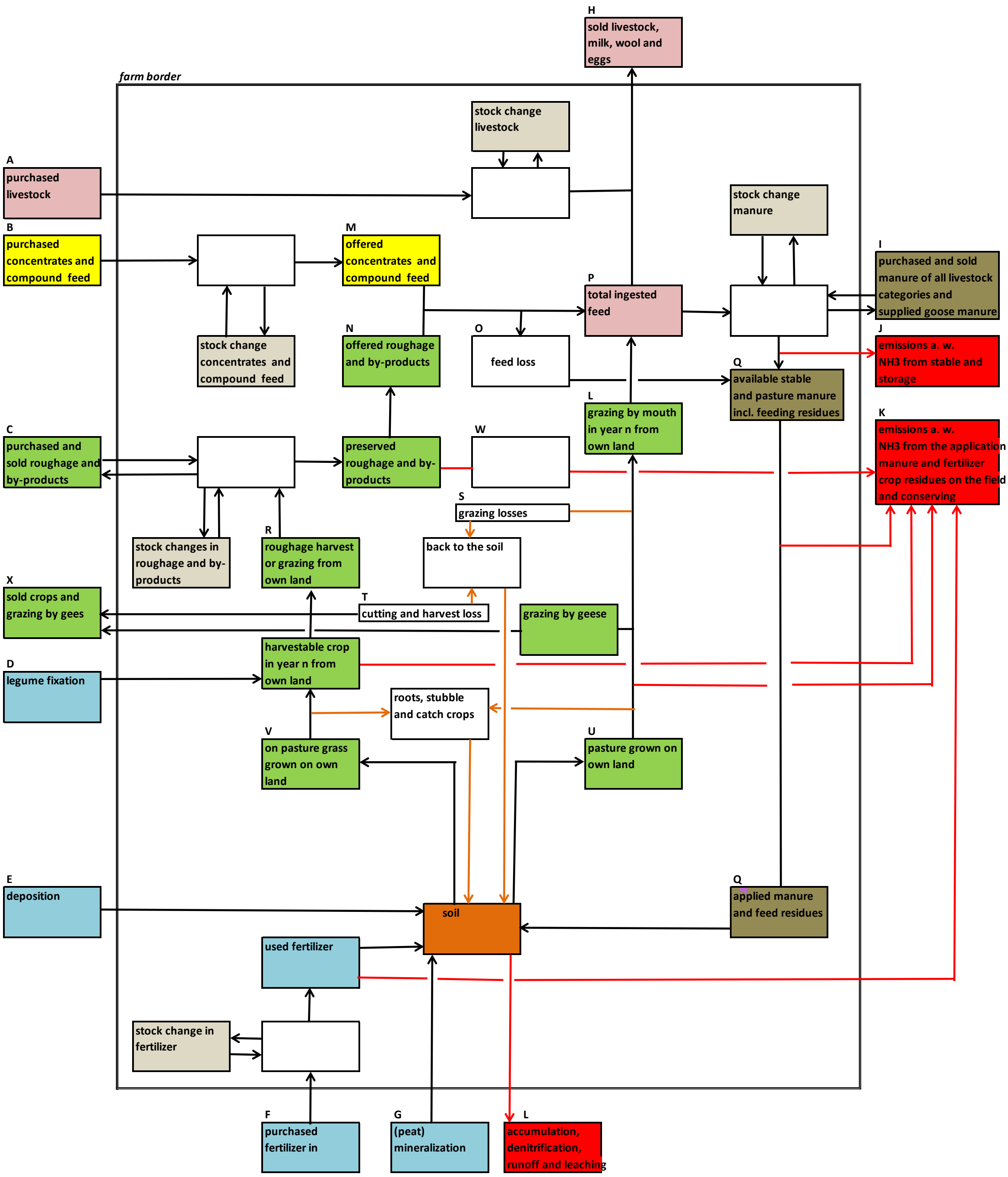

Figure 1.3 *Comprehensive overview of material input and output flows, as well as internal flows, on a farm, with or without arable crop production and other (ruminant/non-ruminant) livestock.*

When farms have more land available per livestock unit, the possibility arises within manure application restrictions to use manure from elsewhere in addition to own manure. In that case, data is required on the composition of the imported manure. Table 1.2 lists the standard values used for this.

Table 1.2 *Average composition (standard values) of organic fertilizers.*

	N (kg / ton)	P_2O_5 (kg / ton)	TAN (% from total N)	SG (ton / m^3)	OS / N -
Ruminants					
slurry	4.0 [1]	1.5 [1]	48 [1]	1.005 [1]	17.8 [1]
manure excreted on pasture[2]	4.0 [1]	1.5 [1]	48 [1]	1.005 [1]	17.8 [1]
solid manure	6.4	3.2	14 [1]	0.9 [1]	20.1 [1]
Non-ruminants					
slurry [3]	6.4	3.8	53 [1]	1.04 [1]	11.3 [1]
solid manure [4]	31.1	15.4	25 [1]	0.605 [1]	12.3 [1]
Compost [5]	7.0 [1]	3.3 [1]	9 [1]	0.8 [6]	30.1 [1]
Liquid fraction	4.9 [1]	2.0 [1]	61 [10]	1.02 [1]	7.0 [1]
Solid fraction	9.2 [1]	8.4 [1]	29 [1]	0.9 [7]	16.5 [1]
Fertilizer substitutes (mineral concentrate, blowdown water)	7.3 [8]	0.5 [8]	90 [8]	1.005 [1]	2.9 [8]
Digestate [9]	5.6 [1]	3.1 [1]	74 [1]	1.005 [1]	6.0 [1]
Other [2]	4.0 [1]	1.5 [1]	48 [1]	1.005 [1]	17.8 [1]
(Ruminants, liquid fraction) [10]	(3.4)	(1.0)	(60)	(1,005)	(13.7)
(Ruminants, solid fraction) [10]	(7.3)	(4.1)	(22)	(0.9)	(26.4)
(Non-ruminants, liquid fraction) [10]	(6.1)	(2.6)	(64)	(1,005)	(8.8)
(Non-ruminants, solid fraction) [10]	(10.8)	(9.1)	(29)	(0.9)	(17.1)

[1] Den Boer *et al.* , 2012.

[2] Same as slurry from ruminants.

[3] Same as slurry from fattening pigs.

[4] Same as solid manure from broilers.

[5] Average of biodegradable municipal waste and green compost.

[6] www.handboekbemesting.nl.

[7] Same as solid manure.

[8] Velthof, 2011.

[9] Average of cattle and fattening pigs and degradation of N-org of 25-50%.

[10] Because the table contains limited plausible values for solid and liquid fractions and this may be due to the use of a limited number of analyzes of different types of manure, the additional figures (between brackets) for solid and liquid fractions may be used in future versions of the ANCA tool. Indicated fractions of 'ruminants' concerns separated cattle manure, and indicated fractions of 'non-ruminants' concerns separate fattening pig manure. The mass balance method was followed as shown in www.bemestingsadvies.nl (consulted on 13 February 2019).

1.3 Sources of N loss

Nitrogen in particular can be lost from the cycle in many forms and from multiple sources. The main forms of loss are ammonia (NH_3-N), nitrous oxide (N_2O-N), nitrate (NO_3-N), elemental nitrogen (N_2), nitrogen oxides (NO_x-N) and organic N (Norg-N) which is stored in the soil. The farm surplus equals the total of the losses in one of the aforementioned forms (the terms J, K and L in Figures 1.2 and 1.3). Table 1.3 shows the sources from which these N connections are mainly lost and the ANCA module in which the loss is numerically calculated. In the context of the ANCA tool, the total calculated N loss (the farm surplus according to Figure 1.2) is categorized into the items:

- NH_3-N loss from (synthetic) fertilizer and dying crop,
- N_2O-N loss from (synthetic) fertilizer, clover, mineralization, soil and silage,
- NO_3-N loss from the soil,
- the calculated other gaseous N losses (N_2, NO_x) from manure storage and silage,
- the non-calculated other N-losses consisting of accumulation of Norg in the soil and / or errors in the previous calculations, as follows:

Non-calculated other N losses = N farm surplus – (NH_3 -N) – (N_2O-N) – (NO_3 -N) - calculated other gaseous N losses.

It should be noted here that it is conveniently assumed that no leaching losses occur from silage and manure storage, but only gaseous losses. This will not be entirely according to reality.

Table 1.3 *Types of N-loss and their source, as well as the module (see superscript) in which the loss is calculated.*

Form	Source:								
	Stable and manure pit	External manure storage	Manure application and grazing	Synthetic fertilizer	Clover	Mineralization	Soil	Crop (seed)	Silage
NH_3-N	X[1]	X[1]	X[1]	X[1]				X[2]	
N_2O-N	X[4]		X[4]	X[4]	X[4]	X[4]	X[4]		
NO_3-N							X[5]		
N_2, NO_x	X[3]								X[3]
Norg							X[6]		

[1] BEA base.

[2] BEA plus.

[3] BEN: non-NH_3 gaseous losses from stable, manure storages and silage.

[4] BEN: nitrous oxide emissions from (synthetic) manure, clover, mineralization and soil.

[5] BEN: nitrate leaching.

[6] BEC: N accumulation as derived from BEC.

1.4 Nutrient use efficiency

1.4.1 General

Nutrient losses are often not only expressed as absolute amount (kg) per unit area (hectare) or per unit product (for example per liter of milk for specialized dairy farms, per kg of nitrogen in the form of removed products for mixed farms, per kg of grain- equivalent for specialized arable farms), but also as the complement of the fraction of an incoming nutrient flow that is not used, i.e. 1 minus the nutrient use efficiency. The nutrient use efficiency can be defined at the level of the farm as a whole and at the level of the underlying internal (sub) flows. It should be noted that any definition is somewhat arbitrary. The value of the ratio of input and output is depending on whether numerator and denominator are expressed as gross flows or as net flows. After all, the fraction 100/200 yields a different number than, for example, the fraction (100+10)/(200+10).

The following efficiency percentages are calculated in the ANCA tool.

1.4.2 Efficiency at farm level

Farm efficiency is defined as:

Produced 'useful' products (milk, meat, arable crops sold, goose-grazed crop) as a fraction of used concentrates, roughage, by-products, legume fixation, deposition, synthetic fertilizer, organic manure (including goose manure) and (peat) mineralization, or (see Figure 1.3):

(H - (A - adjusted for changes in herd size) + X) / ((B - adjusted for changes in stock of concentrate feed) + (C - adjusted for changes in stock of roughage) + D + E + (F - adjusted for changes in the stock of synthetic fertilizer) + (-I - adjusted for changes in the stock of manure) G), with a positive number for the corrections if the stock has increased.

1.4.3 Efficiency at animal level

Animal-level efficiency is defined as:

Produced milk and meat, as a fraction of ingested concentrates, silage, by-products and grass (= feed offered after feed residues have been deducted), or (see Figure 1.3):

(H - (A - corrected for changes in herd size)) / (M + N + L - O)

1.4.4 Efficiency at fertilizer level

The efficiency at fertilizer level is defined as:

Manure and feed residues that end up 'in' the soil, as a fraction of the excretion plus feed residue (= offered feed - milk and meat corrected for changes in herd size) minus changes in the stock of manure (when stock increases), plus manure produced by non-ruminants (based on net excretion of N and P), and reduced by exported / increased with imported manure, or (see Figure 1.3):

(Q) / ((M + N + L) - (H - (A - adjusted for changes in herd size)) - adjusted for changes in the stock of manure - I)

1.4.5 Efficiency at soil level

The efficiency at the soil level is defined as:

Nutrients produced in homegrown crops, including pasture, mowing and harvesting losses and including sold non-roughage arable crops and goose-grazed crops, as a fraction of legume fixation, deposition, articificial fertilizer (after adjusting for stock changes), (peat) mineralization and available manure (including feed residues after deduction of gaseous losses from manure and including goose excretion), or (see Figure 1.3):

((R + T + X) + (L + S)) / (Q + D + E + (F - adjusted for changes in the stock of synthetic fertilizer) + G)

1.4.6 Efficiency at (roughage) crop level

The efficiency at (roughage) crop level, that is, the utilization of roughage until ingestion by animals, is defined as:

Ingested feed from home grown (unsold) and purchased roughage (hence, intake corrected for intake from concentrates), as a fraction of the cultivated and purchased roughage including pasture, harvest and mowing losses, or (see Figure 1.3) :

(P - ((B - corrected for changes in the stock of concentrates) - O_concentrates)) / ((C - adjusted for changes in the stock of roughage) + (R + T) + (L + S))

1.5 Limitations of the ANCA tool

The present version of the ANCA tool has several limitations. Calculations of the effiency at farm level and soil level take into account the 'useful' output in the form of milk and meat from dairy cattle (cows and young stock), as well as 'useful' output from other ruminants (breeding bulls, suckler cows, red meat bulls, rose calves, sheep, goats, horses, ponies) and non-ruminants (pigs, chickens, white veal calves), sold arable products (accounting for the feed used for animals other than dairy cattle), and crops that were grazed by geese. When calculations require figures regarding the use of manure, the manure production of any non-ruminant livestock is settled, but is not calculated - as with dairy cattle - as the difference between the amount of minerals in roughage, concentrates and by-products and the amount of minerals in milk and meat, but estimated based on a total net excretion based on the numbers of animals. Additional calculation rules have been developed with regard to the manure excreted by geese. With regard to greenhouse gases, the present version of the ANCA tool also takes into account greenhouse gas emissions resulting from energy use and enteric methane emissions from non-ruminant livestock.

This version of the ANCA tool does not accurately calculate the conservation losses of silage mixed with by-products and dry by-products. Another shortcoming is that emissions caused by non-ruminant livestock are included in the calculation of ammonia emissions and greenhouse gases per tonne of milk.

1.6 Reading Guide

The following types of excretion and emissions are explained in this report:

- Farm-specific excretion ('BEX'), Section 2.1;
- Farm-specific emissions of ammonia ('BEA'), section 2.2;
- Farm-specific emissions of nitrate and nitrous oxide ('BEN'), Section 2.3;
- Farm-specific phosphate streams ('BEP'), section 2.4;
- Farm-specific carbon currents and emissions of CO_2 equivalents ('BEC'), section 2.5.

Each paragraph starts with an introduction, after which the calculation method for the key figures is explained. Comments are made at the end of each paragraph, including preconditions, limitations and aspects that require refinement or further investigation. Since the flows of N, P and C are related, there is some cross-referencing between sections. In various sections the report contains the words 'stable manure' and 'non-ruminants'. 'Stable manure' refers to all manure excreted indoors (collected, stored), as opposed to manure excreted on pasture. This does not necessarily mean stable manure is solid manure: 'stable manure' can be both slurry and solid manure. The term 'non-ruminants' does not refer to animals kept (partly) indoors, but to animals that are part of intensive livestock raising (pigs, chickens, veal calves). Hence, in this report a dairy herd with no access to pasture is not classified as 'non-ruminants', but as 'ruminants'.

2 Key figures

2.1 Farm-specific excretion (BEX)

2.1.1 Introduction

The BEX, as most recently defined in the National Guidance for Farm-Specific Excretion of Dairy Cattle (2019), calculates the amount of nitrogen (N) and phosphorus (P) in the manure for an individual dairy farm. The calculation has been developed for farms with predominantly dairy cattle and relates to a calendar year. 'Predominantly dairy cattle' means that, in addition to the N and P excretion of the dairy herd (dairy cows and young cattle), the excretion of any other category of ruminants (breeding bulls, suckler cows, red meat bulls, rose calves, sheep, goats, horses, ponies) is also calculated. However, the excretion of the dairy herd is calculated on a farm-specific basis, whereas the excretion of 'other ruminants' is calculated using standard values for excretion (Anonymus, 2015a). The BEX does not calculate the N and P excretion in manure from non-ruminants such as chickens or pigs. The contribution of these animal categories is discussed in section 2.1.3.

The N and P intake of the dairy herd is calculated as the sum of the intake from all feed materials fed to the dairy herd. The net energy (NE) requirement of the animals, corrected for an assumed exceeding of the requirement by 2%, is the starting point for the assumed intake. That is why BEX obliges participating farms to record the quantity of all feed materials and to analyze NE, N and P content and also to analyze the total ash content for grass silage and maize silage. For purchased feed materials quantities are shown on the invoice from the supplier, whereas for homegrown roughage, the quantity, if ensiled, is determined by measuring the silage content (by an accredited sample taker) and assuming a constant density in kg per m^3 based on research by Van Schooten & van Dongen (2007). This research, however, has shown that this 'best practice' to estimate the amount of silage shows large variation in results. Therefore, the estimated amount of silage is therefore insufficiently accurate to determine feed intake from silage. In BEX, therefore, it has been decided to calculate the feed intake of fresh grass, grass silage and silage maize on the basis of the net energy requirement (see section 2.1.2.12). In this calculation the required net energy is allocated to the various feed materials based on the ratio of the (calculated) fresh grass intake and the stocks of grassland products and maize silage products (as determined by an accredited laboratory). This calculation is explained in more detail in Oenema *et al.* (2017).

2.1.2 Calculation method

2.1.2.1 General

The BEX calculates the amount of N and P in manure. For N, volatilization must be taken into account. Therefore, a distinction is made in the BEX between gross and net excretion of N and P. The gross excretion concerns the excretion 'under the tail' and the net excretion is the gross excretion minus the volatilization. For P, volatilization plays no role and the gross excretion is equal to the net excretion.

2.1.2.2 Calculation of gross N and P excretion

The gross ('under the tail') excretion of N and P is calculated in the BEX using the balance method:

Excretion N (or P) = intake N (or P) – retention N (or P)

2.1.2.3 Calculation of intake N and P

Intake N = NE intake x N / NE
Intake P = NE intake x P / NE

Where:

NE intake = NE requirement x 102%. This concerns the total NE requirement of the dairy herd, based on the composition of the dairy herd and the milk production.

N (or P) / NE: NE, N and P are the weighted average of the analyzed average NE, N and P levels in each feed component of the ration.

2.1.2.4 Calculation of N and P retention

This concerns determination of N and P in milk and growing tissue (fetus + adnexa, calf, heifer, first-lactation cow, and second-lactation cow).

Retained N (or P) = kg animal product x N (or P) content of the animal product

The required information consists of a mix of farm-specific information and standard values:

Farm-specific information is available for:
Amount of milk produced, N content in milk, P content in milk (if not available a standard value is used), numbers of animals in the categories of young stock younger than 1 year (calf), young stock older than 1 year (heifer), animals that have calved (dairy cows) and breed of dairy cattle.

Standard values are used for:
P content in milk (if not measured by an accredited institute), N and P retained in the fetus and adnexa, calf, heifer, 1st lactation cow and 2nd lactation cow. Besides this, constants are used for the percentage of pregnant animals (on an annual basis) in the herd in order to calculate N and P retained in fetus and adnexa, for the age structure of the dairy herd to calculate the number of 1st lactation, 2nd lactation and older cows, and for the animal weights of a selected breed.

2.1.2.5 Calculation of net N excretion

The calculated gross N excretion must be corrected for the farm-specific gaseous N losses. These N losses are calculated via BEA (see section 2.2).

Net N excretion = gross N excretion - gaseous N losses from BEA

The required information consists of a mix of farm-specific information and standard values:

Farm-specific information is available for:
Gross N excretion of the dairy herd and per animal category: young stock younger than 1 year, young stock older than 1 year, number of dairy cows including dry cows, share of slurry, and housing type of the dairy cattle.

Standard values are used for the emission percentage for N from manure. The emission percentage for N from manure is calculated via BEA (see standard values in the description of BEA in section 2.2).

2.1.2.6 Age structure dairy herd

The dairy herd consists of several animal categories. Animal numbers are determined per category: dairy cows, dry cows, heads of young stock older than 1 year (heifer), heads of young stock younger than 1 year (calves). Animal categories and counting are laid down in Dutch law (Uitvoeringsbesluit en Uitvoeringsregeling Meststoffenwet). For all animal categories the number is calculated by dividing the total number of the daily counts by 365. Where applicable, a distinction is made between Jersey, Jersey cross breds, and other breeds. A Jersey is an animal with at least 87.5 percent Jersey-blood. A Jersey cross has between 50 and 87.5 percent Jersey-blood.

2.1.2.7 Milk production and milk composition

The milk production is equal to the milk produced in kilograms per year as laid down in Dutch law (Uitvoeringsbesluit Meststoffenwet, Article 33, Uitvoeringsregeling Meststoffenwet, Article 42 and Chapter 9, and Regeling Dierlijke Producten, paragraph 2). The percentage of fat and protein in the milk is the moving average as determined by the dairy industry, calculated per calendar year.
If (part of) the milk is processed on the farm itself, this milk will also be included in the amount of milk produced.

2.1.2.8 Dairy cow weight

The average weight of adult dairy cows determines the net energy required for maintenance of dairy cows, and of the associated young stock. A breed factor is included for this in Table 2.1.1. This is based on the NE maintenance requirement at adult weight.

Table 2.1.1 *Average weight of the different categories of dairy cattle per breed group and the breed factors for the NE requirement and animal weights .*

	Dairy cow weight (kg)	Breed factor[1] NE requirement	Young stock weights (kg)[2]			WT factor[3] breed
Breed	Average		Birth	1 year	At calving	
Jersey	400	0.695	27	197	332	400/650
Cross: Jersey x other breed [4]	525	0.852	36	258	436	525/650
Other breeds	650	1,000	44	320	540	650/650

[1] The breed factor is based on the ratios of the metabolic weights (weight to the power 0.75); The weight of the dairy cow from 'other breeds' is taken as a starting point: WT = 650 kg.

[2/3] The weights of 'Jersey' and 'Cross' can be calculated using the WT factor, based on the average weights of 'Other breeds' , and are rounded.

[4] The 'Cross' is a cross of 'Jersey' x 'Other breed' or 'Other breed' x 'Jersey' .

2.1.2.9 Grazing

Unrestricted grazing refers to cows being grazed day and night (10-20 hours). Restricted grazing refers to cows being grazed only during the daytime or only at night (2-10 hours). For the dairy cows, the number of grazin days per year must be reported for these two systems and (if applicable) the average grazing hours per day for the relevant system.
When dairy cows receive fresh pasture grass in the barn, this is called summer stall feeding. Also in this case, the number of months of summer stall feeding and the number of times that freshly cut grass is offered to cows, day and night ('unrestricted') or only in the daytime or only at night ('restricted').

In addition, a combination of grazing and summer stall feeding may occur. In this case, in addition to the number of days per system, the hours of grazing per day must be specified and it should be indicated whether only fresh grass is fed in the stable ('unrestricted') or, in addition to the fresh grass, roughage is also fed ('restricted').

For young stock, unrestricted grazing is assumed, with the number of grazing days being registered.

The BEX does not record whether dry cows are grazed. The calculation assumes that dry cows are housed all year round and that no fresh grass is provided to this group.

For grass intake one should indicate what part comes from natural grassland. For cows, this should not exceed the share of natural grassland in the total area of grassland. This restriction does not apply to young stock.

2.1.2.10 Calculation of NEL intake and NEL requirement of the dairy herd

The NEL intake is two percent higher than the calculated NEL requirement because it is assumed that the NEL use is 102%. This assumption is consistent with the calculation of standard values for excretion of dairy cattle (Tamminga *et al.* , 2004).
In the present version of the ANCA tool a Dutch net energy system for dairy cattle is used, called 'VEM'. NEL (in kJ) is about the same as VEM * 6.9. The VEM requirement of cattle is calculated using calculation rules of the Dutch institute CVB. These calculation rules are also used to substantiate standard values for excretion in Dutch law (Uitvoeringsregeling Meststoffenwet). The calculation of the VEM requirement takes into account the age structure of the herd, the production level of the cows, the adult weight of the dairy cows, and grazing activity of the dairy cows. The VEM requirement calculation for dairy cattle is based on cattle in tie-stalls. Cattle in freestall barns or grazing have a higher VEM requirement due to the movement activity. In addition, extra energy is required for growth (young animals), pregnancy, and compensation for the Negative Energy Balance (NEB) at the start of lactation. These additional energy needs are included in the total VEM requirement in the form of surplus requirements (see Table 2.1.2).
The VEM requirement of dairy cattle is calculated as the sum of the VEM requirement for milk production and maintenance. For maintenance, a distinction is made between lactating cows and dry cows. The calculation is based on an average of 315 lactation days and a dry period of 50 days per calendar year.
In addition to energy requirements for maintenance and milk production, a cow also uses energy for movement, growth, gestation, and mobilization of body reserves (see Table 2.1.2). The VEM requirement of the total dairy herd (in kVEM / year) is the sum of the VEM requirement of dairy cows, heifers, and calves.

Table 2.1.2 *Energy requirement and surplus requirements in kVEM per cow with an average weight of 650 kg * and per head of young stock.*

		Dairy cows		Young stock	
				≥ 1 year	≤ 1 year
		kVEM / year	kVEM / day	kVEM / day	kVEM / day
Maintenance and milk		See page 18	See page 18	-	-
Maintenance and growth **		-		2259/365	1323/365
Surplus requirements					
Movement ***	No grazing	201			
	extra at Restricted grazing		0.419		
	extra at Combined grazing		0.419		
	extra at Unrestricted grazing		0.560	0.784	0.346
Youth ****		101			
Gestation and NEB *****		194	0.5315	0.2819	

* For a breed with a different adult weight, the surplus requirement in this table must be multiplied with the breed factor VEM requirement belonging to the relevant weight in Table 2.1.1.

* * Only part of the calves stays on the farm all year (after birth). It is necessary to correct for this. The kVEM requirement is therefore not 1,380 but 1,324 kVEM per year. It is assumed that the replacement percentage is 28%, with 0.3760 calves per average dairy cow present, according to the Dutch Dairy Farm Handbook. Per average dairy cow present, the number of calves born alive is 1.14 and the number of calves to be sold at the age of half a month (i.e. 15.2 days) is 0.7653. Converted to the number of calves per year, this means 0.7653 x 15.2 / 365 = 0.0319 calf per average dairy cow present, i.e. 0.3760 + 0.0319 = 0.4079 calves younger than 1 year (category 101) are present per average dairy cow. The requirement in the first month is 54.4 kVEM. Calculated to half a month (15.2 days), the requirement is 54.4 / 2 x 24 = 653 kVEM (rounded) on an annual basis (a year consists of 24 times half a month). The adjusted requirement is 1,380 x 0.3760 / 0.4079 + 653 x 0.0319 / 0.4079 = 1,323.2 kVEM per year. The corrected requirement in the first month is then: (54.4 x (0.3760 + (0.7653 x 0.5))) / 0.4079 = 101.2 kVEM per head of young stock younger than 1 year old.

*** The movement allowance for 'No grazing' applies to non-tethered animals (10% of maintenance requirement, set at 2010 kVEM / year (Tamminga *et al.* , 2004)). The surplus requirement for extra movement in this table for dairy cows is 7.5% for 'restricted grazing' and 10% for 'unrestricted grazing' and for young stock, these are based on the principles in the BEX young stock, which are shown in kVEM per animal per day of grazing. For calves the VEM surplus is specified per average calf present: 0.375 kVEM per day per calf and 0.3760 / 0.4079 = 0.9218 calf of this animal category present all year round, the grazing surplus is 0.375 x 0.3760 / 0.4079 = 0.346 kVEM per day.

**** The youth supplement per cow is calculated for 1^{st} and 2^{nd} lactation cows and is based on 660 VEM per day in the first lactation and 330 VEM in the second lactation. Assuming a replacement percentage of 28%, the total surplus amounts to: (660 + 330) x 365 x 0.28 = 101. For the calculation of the youth surplus for dairy cows, 'other breeds' are based on 540 kg at two years of age, 595 kg. at the age of three and 650 kg at the age of four.

***** The gestation surplus for a dairy cow amounts to (rounded) 144.7 kVEM per year; surplus of a heifer is 90% of that of a dairy cow (144.7 x 0.90 = 130.2 kVEM per year). Assuming an average of 0.70 calves per cow (see Table 2.1.6 on page 23), the gestation surplus is 144.7 x 0.70 = 101.3 kVEM per year. The VEM requirement for the Negative Energy Balance (NEB) is the energy required on average to rebuild body reserves mobilized during the first months of lactation; this amounts to 93 kVEM. The total pregnancy and NEB is therefore 194.3: rounded 194. For a heifer, the gestation surplus is an average of 0.79 calf per heifer (see Table 2.1.4 on page 22), so 144.7 x 0.9 x 0.79 = 102.9 kVEM per year (that is 0.2819 kVEM per day).

Overview calculation rules VEM requirement

kVEM requirement for young stock per year
Younger than 1 year (calves (CA)) (per animal per calendar year): (1,323 + 0.346 x number of grazing days) x number of CA x breed factor VEM requirement (kVEM).

In the VEM requirement, it has been taken into account that not all calves stay on the farm in the year after birth. Many calves leave the farm at an age of (on average) 15 days and therefore contribute with a much lower VEM than the calves that stay on the farm all year. The footnote under Table 2.1.2 describes how this correction is calculated.
Older than 1 year (heifers (HE)) (per animal per calendar year): (2,259 + 130.2 x 0.79 + 0.784 x number of pasture days) x number of HE x breed factor VEM requirement (kVEM) .

kVEM requirement for dairy cows per year: milk production
Milk yield / cow = total milk produced (kg) / the number of dairy cows.
FPCM / day = (milk yield / cow (kg) x (0.337 + 0.116 x fat% + 0.06 x protein%)) / 315 (days).
VEM milk production = (442 x FPCM / day x (1 + (FPCM / day -15) x 0.00165)) x 315 (days).
kVEM milk production = VEM milk production / 1000.

kVEM requirement for dairy cows per year: maintenance
WT (kg) = live weight depending on the type of cow (see table 2.1.1).
VEMmaint during lactation = (42.4 x $WT^{0.75}$ x (1 + (FPCM / day - 15) x 0.00165)) x 315 (days).
VEMmaint during dry period = 42.4 x $WT^{0.75}$ x (1 + (-15 x 0.00165)) x 50 (days).
VEM maintenance dairy cattle = VEMmaint during lactation + VEMmaint during dry period.
kVEM maintenance = VEM maintenance dairy cattle / 1000.

Surplus VEM requirement for dairy cows per year
kVEM surplus per cow = (surplus energy required for movement 'No grazing' from Table 2.1.2 + (number of months of grazing x surplus for extra exercise for 'restricted grazing' or 'unrestricted grazing' from Table 2.1.2) * 315/365) + surplus for ‘youth’ from Table 2.1.2 + surplus for pregnancy and NEB from Table 2.1.2.

kVEM requirement of the dairy herd per year
kVEM requirement of dairy herd = ((kVEM milk production + kVEM maintenance + kVEM surplus) x number of dairy cows) + (kVEM young stock <1 year x number of young stock <1 year) + (kVEM young stock > 1 year x number of young stock > 1 year).

2.1.2.11 Calculation of N and P intake by dairy herd

The N and P intake is calculated by multiplying the VEM intake per feed ingredient by the analyzed N / VEM and P / VEM respectively (see section 2.1.2.3). The total VEM intake is then calculated by adding up results of all feed ingredients. However, on practical farms the VEM intake is often not known for all feed ingredients. For purchased feed ingredients, intake is calculated as the amound purchased minus a change in stock, but homegrown roughage in particular lacks reliable data on the share of pasture grass in the roughage supply. The total energy from homegrown roughage - maize silage, grass silage and fresh (pasture) grass - is estimated as follows:

VEM intake from maize silage, grass silage and fresh (pasture) grass = calculated VEM intake herd - VEM intake from other roughage and wet by-products, concentrates and milk products - feed losses from other roughage and wet by-products, concentrates and dairy products, with:

calculated VEM intake herd = VEM herd requirement x 102%.

2.1.2.12 Calculation of VEM intake from maize silage, grass silage and fresh grass

Dividing the total calculated VEM intake from maize silage, grass silage and fresh (pasture) grass over these 3 individual products is done by calculating a ratio between a calculated VEM intake from fresh grass, a measured amount of grass silage fed, and a measured amount of maize silage fed.

I. For fresh (pasture) grass, both intake and feeding values are not available. Depending on the grazing system, a dry matter intake from fresh grass is calculated for the VEM intake from fresh (pasture) grass (Oenema *et al.* , 2017). The following principles are used in the calculation:

- The variation in grazing duration with unrestricted grazing is 10 to 20 hours per day. This variation is limited to 2 to 10 hours per day for restricted grazing.
- In practice, grazing dairy cows are grazed at least two hours. During 2 hours of grazing, a dairy cow absorbs 2 kg of dry matter grass (type 'Other breeds' - see Tables 2.1.1 and 2.1.2 - and with a milk production of 9,500 kg FPCM / year). Additional grazing per hour adds 0.75 kg of dry matter, with a maximum of 18 additional grazing hours (20h in total) per day. For every 500 kg FPCM more (or less), the dry matter intake from pasture grass must be increased (or decreased) by 2%.
- In summer stall feeding, it is assumed that the dry matter intake of a dairy cow with 'unrestricted' access amounts to 87% of the intake in unrestricted grazing for 20 hours per day. For a dairy cow with 'restricted' access to fresh grass in summer stall feeding, the dry matter intake of fresh grass is equal to 87% of the intake during 9 hours of grazing per day.
- The dry matter intake of Jerseys and crossbreeds is 70% and 85% of that of cows of 'other breeds', respectively. The same percentages apply to the reference level of the milk production to calculate dry matter intake (6650 and 8075 kg FPCM / year respectively).
- Dry cows do not receive fresh grass.

2.1.2.13 Calculation of the N/VEM and P/VEM ratio in fresh grass

The composition of fresh pasture grass (dry matter, VEM, N and P) in pastures and in summer stall feeding is unknown. In the BEX, a distinction is made between fresh grass from production grassland (production grass) and fresh grass from natural grassland (natural grass). The ratio of VEM, N and P in fresh 'production grass' is derived from the N / VEM and P / VEM in grass silage (based on research in practical farms; project 'Koeien & Kansen'). In this case, the quality of the grass silage(s) should be representative of the quality of the fresh grass fed to dairy cows via grazing or summer stall feeding. Therefore, the ratio between VEM, N and P in grassland products (only grass silage, excl. purchased grass, and not from natural pastures) is the starting point for the estimated composition of the fresh 'production grass'. If grass silage is not available on the farm, standard values are used (based on data from the project mentioned above). For fresh 'natural grass', standard values are derived from other research (Vellinga, 1994; Korevaar et al., 2006).

Correction for feed intake by other ruminants

If, in addition to dairy cows and associated young stock ('dairy cattle'), other ruminants are present on the farm and the feed for these ruminants is not clearly separated from the feed for dairy cattle, this amount will be deducted from the total intake, using standard values for feed intake by other ruminants (Table 2.1.3). This includes feed intake and feeding losses.

Furthermore, attention should be paid to the distribution of feed over animal categories in Table 2.1.3. In principle, the total kVEM intake per animal category is used. However, if one or more feed categories are not fed on a farm, the kVEM intake per animal category should be based on other feed categories, which are listed per animal category. This is done as follows, always in a specific order, as stated below:

- In case of no fresh (pasture) grass: grass products, maize silage, other products, concentrates, milk powder. This applies, for example, if cows that are normally grazed are not grazed because of a lack of pasture grass. In this case, it is assumed that the kVEM requirement of 1,792 kVEM from pasture grass comes from grass products, hence the intake still amounts to 3,187 kVEM;

- In case of no or insufficient artificial milk powder: concentrates, other products, maize silage, grass products, fresh pasture grass;
- In case of no or insufficient concentrates: other products, maize silage, grass products, fresh pasture grass, artificial milk powder;
- In case of no or insufficient other products: maize silage, grass products, fresh pasture grass, concentrates, milk powder;
- In case of no or insufficient maize silage: other products, grass products, fresh pasture grass, concentrates, milk powder;
- In case of no or insufficient grass products: other products, maize silage, fresh pasture grass, concentrates, milk powder.

Table 2.1.3 *Standard values kVEM intake per year for a number of categories of 'other ruminants'.*

Animal category	Feed							
	Artificial milk	Concent-rates	Roughage				Others	Total roughage and other
			Fresh grass	Hay Grass silage	Green corn silage	Total		
104 Breeding bulls (> 1 year)	0	274	0	2466		2466		2740
115 Calves for rosé or red meat (<approx. 3 months)	222	406	0	0	140	140	0	768
116 Rose calves (approx. 3 months to approx. 8 months)	0	1122	0	0	655	655	355	2132
117 rosé calves (approx. 14 days to 8 months)	78	880	0	0	482	482	211	1651
120 Pasture and suckler cows	0	56	1792	1339	0	3131	0	3187
122 Beef bulls (> 3 months to slaughter)	0	970	0	0	1652	1652	68	2690
550 Breeding sheep (lambed at least once incl. Lambs <approx. 4 months and rams)	0	56	328	65	0	393	0	449
551 Meat sheep (<approx. 4 months, not born on farm)	0	9	47	4	0	51	0	60
552 Rearing ewes, pasture sheep, meat sheep (> approx. 4 months)	0	11	266	22	0	288	0	299
600 Dairy goats (lambed at least once incl. newborn lambs and mature bucks)	0	419	0	149	279	428	0	847
601 Rearing goats and meat goats (<approx. 4 months)	54	65	0	38	70	108	0	227
602 Rearing goats and meat goats (> approx. 4 months)	0	162	0	94	173	267	0	429
941 Ponies	0	247	671	673	0	1344	0	1591
943 Horses	0	437	1019	906	0	1925	125	2487

[1] For an exact description, see Appendix D of the Dutch Fertilizers Act ('Uitvoeringsregeling Meststoffenwet').

[2] Dry concentrates: compound concentrate feeds plus single dry concentrate feeds.

[3] Grass hay, grass silage and / or grass chunks; this category should actually be called 'other grass products' ; it has already been made clear in the foregoing what this feed category entails.

[4] Moist concentrates plus other roughages. The stated values for rosé calves are based on moist concentrates.

2.1.2.14 Overview of calculation rules for N and P intake

VEM value of fresh production grass = 960 VEM / kg DS

N / VEM and P / VEM fresh production grass:

N / VEM pasture grass = 1.12 x N / VEM ensiled grass

P / VEM pasture grass = 0.97 x P / VEM ensiled grass

N / VEM summer stall feeding = 1.06 x N / VEM ensiled grass

P / VEM summer stall feeding = 0.98 x P / VEM ensiled grass

Contents in fresh production grass if grass silage is not available:
VEM value of fresh production grass = 960 VEM / kg DS
N content of fresh production grass = 213 / 6.25 g / kg
P content of fresh production grass = 4.4 g / kg DS
VEM value fresh natural grass = 860 VEM / kg DS
N content of fresh natural grass = 189 / 6.25 g / kg DS
P content of fresh natural grass = 4.0 g / kg DS

Calculation of the amount of intake from pasture grass

milk factor = 1 + (milk production - 9,500 * breed factor) / 500 x 0.02

In grazed herds:
kVEM intake of dairy herd from fresh grass =
(number of grazing days of dairy cows) x ((2 + 0.75 x (grazing hours / day - 2)) x milking factor) x number of dairy cows x VEM value grazed grass / 1,000
the following applies: number of grazing hours / day ≤ 20

For summer stall feeding:
kVEM intake of dairy herd from fresh grass =
kVEM intake dairy herd from fresh grass when grazing x 0.87 =
(number of days summer stall feeding of dairy cows) x ((2 + 0.75 x (grazing hours / day - 2)) x milk factor x 0.87) x number of dairy cows x VEM value grazed grass / 1,000

The following applies to this:
Number of grazing hours / day = 20 with 'unrestricted' access to fresh grass in the stable.
Number of grazing hours / day = 9 with 'restricted' access to fresh grass in the stable.

N and P retention
N and P retention is calculated for the entire dairy herd: all lactating and dry cows, plus the young stock. No additional data is required; all calculations are done with standard values, except for N and P retained in milk and the numbers of animals (Tables 2.1.4 and 2.1.5).

Table 2.1.4 *Principles for N and P retention in dairy herd.*

Live weights of dairy herd age categories	Abbreviation
Weight adult dairy cow* = WT	WT
Weight calf (kg) ** = WT x 44/650	WTcalf
Weight heifer (kg) ** = WT x 320/650	WTheif
Weight first-lactation cow (kg) ** = WT x 540/650	WT1lact
N and P retention in dairy cows	
Milk production	
Nitrogen (N) content in milk (g / kg) = protein% in milk x 10 / 6.38	
Phosphorus (P) content in milk (g / kg) = phosphorus content in milk / 100	
Gestation	
Number of calves born per cow per calendar year = 0.70	Ncalf
Nitrogen (N) calf content (g / kg) = 29.4	Ncontcalf
Phosphorus (P) calf content (g / kg) = 8.0	Pcontcalf
N and P contents of calves concern the composition at birth	
Growth of (lactating) heifers (replacement)	
Share of replacement per dairy cow = 0.28	replacement
Nitrogen (N) content first-lactation cow (g / kg) = 23.1	Ncont1lact
Phosphorus (P) content first-lactation cow (g / kg) = 7.4	Pcont1lact

Live weights of dairy herd age categories	Abbreviation
Nitrogen (N) content cow (g / kg) = 22.5	Ncontcow
Phosphorus (P) content cow (g / kg) = 7.4	Pcontcow
N and P content of first-lactation cows concern composition at first calving	
N and P retention in young stock	
Young stock less than one year old	
Nitrogen (N) content calf (g / kg) = 29.4	Ncontcalf
Phosphorus (P) content calf (g / kg) = 8.0	Pcontcalf
Nitrogen (N) content heifer (g / kg) = 24.1	Ncontheif
Phosphorus (P) content heifer (g / kg) = 7.4	Pcontheif
N and P content of heifer concern composition at 12 months of age	
Young stock more than one year old	
Number of calves born from young stock per calendar year = 0.79	Ncalf1
Nitrogen (N) content calf (g / kg) = 29.4	Ncontcalf
Phosphorus (P) content calf (g / kg) = 8.0	Pcontcalf
Nitrogen (N) content heifer (g / kg) = 24.1	Ncontheif
Phosphorus (P) content heifer (g / kg) = 7.4	Pcontheif
Nitrogen (N) content first-lactation cow (g / kg) = 23.1	Ncont1lact
Phosphorus (P) content first-lactation cow (g / kg) = 7.4	Pcont1lact

* The average body weight of an adult dairy cow depends on the breed: see Table 2.1.1. For 'other breeds' this is 650 kg.

** For 'other breeds' (Table 2.1.1), the average weight of a calf (at birth) is 44 kg, a heifer 320 kg at one year of age and 540 kg at calving (at the age of approximately 26 months).

Table 2.1.5 *Calculation of N and P retention (in kg per year) *.*

Retention in dairy cows
During milk production
Nmilk = (total milk delivered x (protein percentage x 10 / 6.38)) / 1,000
Pmilk = (total milk delivered x 0.97) / 1,000
During pregnancy
WTcalf = WT x 44/650
Ncalf = ((WTcalf x Ncalf ** x Ncontcalf) / 1,000) x number of dairy cows
Pcalf = ((WTcalf x Ncalf ** x Pcontcalf) / 1,000) x number of dairy cows
Growth of (lactating) first-lactation cows (replacement)
WTheif = WT x 540/650
N1lact = (WT1lact x replacement x Ncont1lact **) / 1,000
P1lact = (WT1lact x replacement x Pcont1lact **) / 1,000
Ncow = (WT x replacement x Ncontcow **) / 1,000
Pcow = (WT x replacement x Pcontcow **) / 1,000
Nrepl = (Ncow – N1lact) x number of dairy cows
Prepl = (Pcow – P1lact) x number of dairy cows
Retention in young stock
Younger than 1 year old
WTheif = WT x 320/650
Ncalf1 = (WTcalf x Ncontcalf ***) / 1,000
Pcalf1 = (WTcalf x Pcontcalf ***) / 1,000
Nheif = (WTheif x Ncontheif ***) / 1,000
Pheif = (WTheif x Pcontheif ***) / 1,000
Nys <1 = (Nheif - Ncalf1) x avg. number of young stock <1yr x Ncorr
Pys <1 = (Pheif - Pcalf1) x avg. number of young stock <1yr x Pcorr
NCorr = 0.971 ****
Pcorr = 0.961 ****
Older than 1 year old
Ncalf2 = (WTcalf x Ncalf1 ** x Ncontcalf ***) / 1,000
Pcalf2 = (WTcalf x Ncalf1 ** x Pcontcalf ***) / 1,000

Retention in dairy cows
N1lact1 = (WT1lact x Ncont1lact ***) / 1,000
P1lact1 = (WT1lact x Pcont1lact ***) / 1,000
Nys> 1 = (NcalfO + (N1lact1 – Nheif) x12 / 14) x avg. heads of young stock> 1yr.
Pys> 1 = (PcalfO + (P1lact1 – Pheif) x 12/14) x avg. heads of young stock> 1yr

* Formulas (and abbreviations) are linked to those in Table 2.1.4.

** For Ncalf and Ncalf1 see Table 2.1.4; Ncalf = average number of calves born per year in cows; Ncalf1 = average number of calves born per year from young cattle.

*** For N and P contents of cow, 1st lactation cow, heifer, and calf, see Table 2.1.4.

****These correction factors for N and P retention are used because that not all calves stay on the farm in their first year after birth. Many are removed at an age of (on average) 15 days and thus considerably less N and P is retained than in animals that remain on the farm a whole year.

2.1.2.15 Gaseous N losses

Part of the nitrogen excretion of the dairy herd is lost from barns and manure storages through volatilization. As manure-N application standards are based on the quantity after deduction of gaseous losses, these gaseous N losses must be taken into account. Gaseous N losses are calculated in the BEA module of the ANCA tool (section 2.2).

2.1.3 Manure production by ‘other ruminants’

The quantities of manure-N and manure-P_2O_5 excreted by other ruminants are based on standard values in the ANCA tool (Table 2.1.6), with a distinction for manure-N between conventional and organic dairy farming systems. These standard values are net excretions, hence gaseous N losses are already deducted. For these excretions, too, they are first converted into gross excretions in the ANCA tool to calculate the soil N surplus by accounting for the gaseous N-losses using the BEA module.

Table 2.1.6 *Net excretion in the form of manure-N and manure-P_2O_5 per average animal present for 'other ruminants' (source: RVO).*

Animal category	Slurry N excretion	Solid manure N excretion	OrganicN excretion	P_2O_5-excretion
Breeding bulls> 1 year (cat. 104)	72.2	72.2	51	25.9
Pasture and suckler cows (cat. 120)	75.4	75.3	66.2	26.9
Calves for rosé or red meat (cat. 115)	10.5	10.5	6.6	3.4
Rosé calves, 3 months - slaughter (cat. 116)	26.3	26.3	26.3	9.4
Rosé calves, 2 weeks - slaughter (cat. 117)	21.5	21.5	21.5	7.6
Red meat bulls, 3 months - slaughter (cat. 122)	28.2	25.6	27.2	9.7
Breeding sheep (cat. 550)	9.9	9.9	10.3	3.3
Meat sheep, <4 months (cat. 551)	0.9	0.9	0.9	0.3
Other sheep,> 4 months (cat. 552)	7.2	7.2	9.3	2.2
Milk goats (cat. 600)	10.2	10.2	5.8	4.3
Rearing and meat goats, <4 months (cat. 601)	0.9	0.9	0.9	0.4
Rearing and meat goats,> 4 months (cat. 602)	7.4	7.4	3.1	3.1
Ponies (cat. 941)	29.3	29.3	29.3	11.7
Horses (cat. 943)	53.7	53.7	53.7	22.4

2.1.4 Manure production by ‘non ruminants’

For calculation of some key figures the ANCA tool takes into account the presence of ‘non-ruminants'. For this reason data is needed on the contribution of these 'non-ruminants' to the excretion, removal and possible use of N and P in this form of animal manure. These are not calculated through information about quantities and composition of purchased feed and other material and quantities and composition of exported animals or products, but by directly requesting data about the net farm balance(s) available in other monitoring systems. This is based on net production of manure N, that is after deduction of gaseous N losses from the barn and storage. For these excretions, too, they are first converted into gross excretions in the ANCA tool to calculate the soil N surplus by accounting for gaseous N-losses calculated with the BEA module. The environmentally harmful part of the emissions (ammonia-N, nitrous oxide-N, methane) from 'non-ruminants' is added to the emissions of the rest of the farm. With regard to methane emissions this applies both to the methane emitted from manure in barns and manure storage facilities, and to the enteric methane emitted during digestion. Emissions are estimated using emissions coefficients and numbers of animals present (Mosquera & Hol, 2012; Anonymus, 2015b).

The calculation of manure N and P excretion by 'non-ruminants' requires the following information:

- Total net excretion nitrogen and phosphate (fertilization plan)
- Average number of animals present (AN)
- Type of manure (slurry or solid manure)
- Housing system (categories as defined in the Dutch Ammonia and Animal Husbandry regulation (‘RAV’); see table 2.1.7)
- The total amounts of nitrogen and phosphate from the total net excretion is divided over the different animal groups via a weighted average of normative nitrogen and phosphate excretions calculated using manure production and manure composition in Table 2.1.7:
  - Normative production of nitrogen = AN * manure production per AN * N content of manure
  - Normative production of phosphate = AN * manure production per AN * P_2O_5 content of manure
- The amount of manure in tons is calculated using Table 2.1.7:
  - Normative manure production = AN * manure production per AN
- Two types of 'manure' are distinguished in ANCA: slurry and solid manure. It is therefore necessary to indicate whether the relevant animal category produces slurry or solid manure. The total nitrogen and phosphate production in slurry and solid manure can be determined by adding up the net excretion among the livestock.
- Finally, the N and P content is determined by dividing the amounts of nitrogen and phosphate by the amount of manure.

Table 2.1.7 *Normative net manure productions and manure contents for different types of livestock and housing systems (housing systems belonging to Rav codes are listed here: https://wetten.overheid.nl/BWBR0013629/2020-07-01)*

Livestock species	Rav code stable	Manure production slurry (tons per AN) (kg / AN)	Manure production solid manure (kg / AN)	Nitrogen content slurry (kg N / ton)	Nitrogen content solid manure (kg N / ton)	Phosphate content slurry (P_2O_5 / ton)	Phosphate content solid manure (kg P_2O_5 / ton)
Laying hens	E 2.5.6	43.7	14.56	16.82	50.75	6.0	18.8
	E 2.7	43.7	15.6	11.23	31.69	6.0	24.2
	E 2.8	43.7	15.6	15.25	42.96	6.0	24.2
	E 2.9.1	43.7	15.6	14.95	42.14	6.0	24.2
	E 2.9.2	43.7	15.6	14.46	40.76	6.0	24.2
	E 2.9.3	43.7	15.6	14.46	40.76	6.0	24.2
	E 2.10	43.7	15.6	16.78	47.25	6.0	24.2
	E 2.11.1	43.7	18.72	15.64	36.72	6.0	24.2
	E 2.11.2	43.7	18.72	16.33	38.32	6.0	24.2
	E 2.11.3	43.7	18.72	16.92	39.70	6.0	24.2
	E 2.11.4	43.7	18.72	16.68	39.15	6.0	24.2
	E 2.12.1	43.7	15.6	16.07	45.27	6.0	24.2

Livestock species	Rav code stable	Manure production slurry (tons per AN) (kg / AN)	Manure production solid manure (kg / AN)	Nitrogen content slurry (kg N / ton)	Nitrogen content solid manure (kg N / ton)	Phosphate content slurry (P_2O_5 / ton)	Phosphate content solid manure (kg P_2O_5 / ton)
	E 2.12.2	43.7	15.6	15.33	43.18	6.0	24.2
	E 2.13	43.7	15.6	15.54	43.79	6.0	24.2
	E 2.14	43.7	15.6	15.54	43.79	6.0	24.2
	E 2.15	43.7	15.6	15.54	43.79	6.0	24.2
	E 2,100	43.7	15.6	11.23	31.69	6.0	24.2
Broilers	E 5.1	19.2	11.4	25.47	43.11	6.0	16.6
	E 5.2	19.2	11.4	25.00	42.32	6.0	16.6
	E 5.3	19.2	11.4	25.47	43.11	6.0	16.6
	E 5.4	19.2	11.4	25.31	42.85	6.0	16.6
	E 5.5	19.2	11.4	23.38	39.59	6.0	16.6
	E 5.6	19.2	11.4	23.79	40.29	6.0	16.6
	E 5.7	19.2	11.4	24.47	41.44	6.0	16.6
	E 5.8	19.2	11.4	24.68	41.79	6.0	16.6
	E 5.9.1.2.2	19.2	11.4	24.00	40.65	6.0	16.6
	E 5.9.1.2.4	19.2	11.4	24.16	40.91	6.0	16.6
	E 5.10	19.2	11.4	23.90	40.47	6.0	16.6
	E 5.11	19.2	11.4	24.63	41.70	6.0	16.6
	E 5.12	19.2	11.4	24.47	41.44	6.0	16.6
	E 5.13	19.2	11.4	24.47	41.44	6.0	16.6
	E 5.14	19.2	11.4	23.90	40.47	6.0	16.6
	E 5.15	19.2	11.4	25.1	42.50	6.0	16.6
	E 5,100	19.2	11.4	21.54	36.50	6.0	16.6
Farrowing sows	D 1.2.1	4003	2356	5.88	9.87	2.5	13.6
	D 1.2.2	4003	2356	5.79	9.71	2.5	13.6
	D 1.2.3	4003	2356	5.72	9.59	2.5	13.6
	D 1.2.4	4003	2356	5.93	9.94	2.5	13.6
	D 1.2.5	4003	2356	5.90	9.90	2.5	13.6
	D 1.2.6	4003	2356	5.72	9.59	2.5	13.6
	D 1.2.7	4003	2356	5.49	9.20	2.5	13.6
	D 1.2.8	4003	2356	5.93	9.94	2.5	13.6
	D 1.2.9	4003	2356	6.07	10.18	2.5	13.6
	D 1.2.10	4003	2356	6.07	10.18	2.5	13.6
	D 1.2.11	4003	2356	6.07	10.18	2.5	13.6
	D 1.2.12	4003	2356	6.09	10.22	2.5	13.6
	D 1.2.13	4003	2356	5.97	10.02	2.5	13.6
	D 1.2.14	4003	2356	5.97	10.02	2.5	13.6
	D 1.2.15	4003	2356	6.55	11.00	2.5	13.6
	D 1.2.16	4003	2356	5.97	10.02	2.5	13.6
	D 1.2.17.1	4003	2356	6.3	10.7	2.5	13.6
	D 1.2.17.2	4003	2356	6.1	10.2	2.5	13.6
	D 1.2.17.3	4003	2356	6.36	10.67	2.5	13.6
	D 1.2.17.4	4003	2356	6.36	10.67	2.5	13.6

Livestock species	Rav code stable	Manure production slurry (tons per AN) (kg / AN)	Manure production solid manure (kg / AN)	Nitrogen content slurry (kg N / ton)	Nitrogen content solid manure (kg N / ton)	Phosphate content slurry (P_2O_5 / ton)	Phosphate content solid manure (kg P_2O_5 / ton)
	D 1.2.17.5	4003	2356	6.3	10.7	2.5	13.6
	D 1.2.17.6	4003	2356	6.5	10.8	2.5	13.6
	D 1.2.18	4003	2356	6.26	10.51	2.5	13.6
	D 1.2.19	4003	2356	6.45	10.84	2.5	13.6
	D 1.2.20	4003	2356	6.3	10.7	2.5	13.6
	D 4.1	4003	2356	5.28	8.85	2.5	13.6
	D 1.2.100	4003	2356	4.73	7.90	2.5	13.6
Other sows	D 1.3.1	2400	1413	6.17	10.34	2.5	13.6
	D 1.3.2	2400	1413	6.38	10.70	2.5	13.6
	D 1.3.3	2400	1413	6.13	10.28	2.5	13.6
	D 1.3.4	2400	1413	6.38	10.70	2.5	13.6
	D 1.3.5	2400	1413	6.24	10.46	2.5	13.6
	D 1.3.6	2400	1413	6.56	11.00	2.5	13.6
	D 1.3.7	2400	1413	6.56	11.00	2.5	13.6
	D 1.3.8	2400	1413	6.24	10.46	2.5	13.6
	D 1.3.9.1	2400	1413	6.2	10.4	2.5	13.6
	D 1.3.9.2	2400	1413	6.1	10.3	2.5	13.6
	D 1.3.10	2400	1413	6.10	10.22	2.5	13.6
	D 1.3.11	2400	1413	6.94	11.65	2.5	13.6
	D 1.3.12.1	2400	1413	6.8	11.4	2.5	13.6
	D 1.3.12.2	2400	1413	6.6	11.0	2.5	13.6
	D 1.3.12.3	2400	1413	6.8	11.4	2.5	13.6
	D 1.3.12.4	2400	1413	6.8	11.4	2.5	13.6
	D 1.3.12.5	2400	1413	6.8	11.4	2.5	13.6
	D 1.3.12.6	2400	1413	6.9	11.5	2.5	13.6
	D 1.3.13	2400	1413	6.79	11.40	2.5	13.6
	D 1.3.14	2400	1413	6.87	11.53	2.5	13.6
	D 1.3.15	2400	1413	6.2	10.5	2.5	13.6
	D 4.1	2400	1413	5.95	9.98	2.5	13.6
	D 1.3.100	2400	1413	5.53	9.26	2.5	13.6
Weaned piglets	D 1.1.1	535	343	6.78	10.44	3.9	13.6
	D 1.1.2	535	343	6.69	10.31	3.9	13.6
	D 1.1.3	535	343	6.86	10.58	3.9	13.6
	D 1.1.4.1	535	343	6.7	10.3	3.9	13.6
	D 1.1.4.2	535	343	6.6	10.1	3.9	13.6
	D 1.1.5	535	343	6.46	9.94	3.9	13.6
	D 1.1.6	535	343	6.81	10.50	3.9	13.6
	D 1.1.7	535	343	6.69	10.31	3.9	13.6
	D 1.1.8	535	343	6.73	10.37	3.9	13.6
	D 1.1.9	535	343	6.76	10.42	3.9	13.6
	D 1.1.10	535	343	6.76	10.42	3.9	13.6
	D 1.1.11	535	343	6.83	10.52	3.9	13.6

Livestock species	Rav code stable	Manure production slurry (tons per AN) (kg / AN)	Manure production solid manure (kg / AN)	Nitrogen content slurry (kg N / ton)	Nitrogen content solid manure (kg N / ton)	Phosphate content slurry (P_2O_5 / ton)	Phosphate content solid manure (kg P_2O_5 / ton)
	D 1.1.12.1	535	343	6.8	10.5	3.9	13.6
	D 1.1.12.2	535	343	6.8	10.4	3.9	13.6
	D 1.1.12.3	535	343	6.8	10.5	3.9	13.6
	D 1.1.13	535	343	6.78	10.44	3.9	13.6
	D 1.1.14	535	343	7.06	10.89	3.9	13.6
	D 1.1.15.1	535	343	7.0	10.7	3.9	13.6
	D 1.1.15.2	535	343	6.8	10.4	3.9	13.6
	D 1.1.15.3	535	343	7.0	10.7	3.9	13.6
	D 1.1.15.4	535	343	7.0	10.7	3.9	13.6
	D 1.1.15.5	535	343	7.0	10.7	3.9	13.6
	D 1.1.15.6	535	343	7.0	10.8	3.9	13.6
	D 1.1.16	535	343	6.95	10.71	3.9	13.6
	D 1.1.17	535	343	7.00	10.79	3.9	13.6
	D 4.1	535	343	6.29	9.68	3.9	13.6
	D 1.1.100	535	343	5.95	9.15	3.9	13.6
Fattening pigs	D 3.1	1337	974	6.12	8.26	3.9	13.6
	D 3.2.1	1337	974	6.12	8.26	3.9	13.6
	D 3.2.2	1337	974	7.96	10.79	3.9	13.6
	D 3.2.3	1337	974	7.90	10.70	3.9	13.6
	D 3.2.4	1337	974	8.34	11.31	3.9	13.6
	D 3.2.5	1337	974	8.15	11.05	3.9	13.6
	D 3.2.6	1337	974	8.03	10.88	3.9	13.6
	D 3.2.7.1	1337	974	8.34	11.31	3.9	13.6
	D 3.2.7.2	1337	974	8.03	10.88	3.9	13.6
	D 3.2.8	1337	974	8.41	11.40	3.9	13.6
	D 3.2.9	1337	974	8.41	11.40	3.9	13.6
	D 3.2.10	1337	974	8.09	10.97	3.9	13.6
	D 3.2.11	1337	974	7.90	10.70	3.9	13.6
	D 3.2.12	1337	974	8.22	11.14	3.9	13.6
	D 3.2.13	1337	974	7.90	10.70	3.9	13.6
	D 3.2.14	1337	974	8.88	12.06	3.9	13.6
	D 3.2.15.1	1337	974	8.7	11.8	3.9	13.6
	D 3.2.15.2	1337	974	8.4	11.4	3.9	13.6
	D 3.2.15.3	1337	974	8.7	11.8	3.9	13.6
	D 3.2.15.4	1337	974	8.7	11.8	3.9	13.6
	D 3.2.15.5	1337	974	8.7	11.8	3.9	13.6
	D 3.2.15.6	1337	974	8.8	11.9	3.9	13.6
	D 3.2.16	1337	974	8.28	11.23	3.9	13.6
	D 3.2.17	1337	974	8.69	11.79	3.9	13.6
	D 3.2.18	1337	974	8.79	11.92	3.9	13.6
	D 4.1	1337	974	7.63	10.33	3.9	13.6

Livestock species	Rav code stable	Manure production slurry (tons per AN) (kg / AN)	Manure production solid manure (kg / AN)	Nitrogen content slurry (kg N / ton)	Nitrogen content solid manure (kg N / ton)	Phosphate content slurry (P_2O_5 / ton)	Phosphate content solid manure (kg P_2O_5 / ton)
	D 3,100	1337	974	7.07	9.57	3.9	13.6
White meat calves	A 4.1	2743	2469	4.98	5.46	1.4	4.3
	A 4.2	2743	2469	4.73	5.19	1.4	4.3
	A 4.3	2743	2469	4.73	5.19	1.4	4.3
	A 4.4	2743	2469	5.03	5.52	1.4	4.3
	A 4.5.1	2743	2469	4.92	5.40	1.4	4.3
	A 4.5.2	2743	2469	4.73	5.19	1.4	4.3
	A 4.5.3	2743	2469	4.92	5.40	1.4	4.3
	A 4.5.4	2743	2469	4.92	5.40	1.4	4.3
	A 4.5.5	2743	2469	4.92	5.40	1.4	4.3
	A 4.5.6	2743	2469	4.98	5.46	1.4	4.3
	A 4.6	2743	2469	4.92	5.40	1.4	4.3
	A 4.7	2743	2469	4.28	4.69	1.4	4.3
	A 4.8	2743	2469	4.5	4.9	1.4	4.3
	A 4,100	2743	2469	3.96	4.33	1.4	4.3

2.1.5 Manure separation

To calculate the composition of animal manure separated into a liquid and solid fraction, principles and assumptions are used as decribed in Schröder *et al.* (2009) and Den Boer *et al.* (2012). It is assumed that organically bound N (Norg) and phosphorus (P) are associated with organic matter and ammonium N (NH_4-N, Nmin) with water. The 'separation efficiency' determines to what extent an element in the incoming manure eventually ends up in the solid fraction. Based on this principle, the separation efficiency consists of two key figures:

1. Percentage of dry matter (DM) going to the solid fraction
2. The DM content in the solid fraction (kg / ton)

The separation efficiency of P varies in simple methods from 30 to 60% (Schröder *et al.* , 2009). A separation efficiency of P of 60% means that 60% of the P (as assumed part of the DM) goes to the solid fraction and that 40% remains in the liquid fraction (key figure 1). The solid fraction usually contains no more than 200-350 kg DS / ton (key figure 2).

The N/P ratio in the farm's own manure is determined on the basis of the N/P ratio in the net excretion according to the BEX, that is after deduction of the gaseous losses. The amount and composition of the (own) manure on the farm (volume and contents of DS, Norg, Nmin, P) is then derived based on the TAN excretion (BEA), corrected for the amount of exported removed in terms of N and P, combined with standard values for volume production per type of manure (slurry and solid manure (; RVO- Table 6). This calculated composition is then the basis for the incoming manure for manure separation, based on the two indicators, and an estimate can then be made of the contents of TAN, organic N (N-total - TAN) and P in the liquid and solid fractions. The ratio N / P in livestock manure is based on the net excretion (see section 2.1.4).

In practice, it appears to be difficult to properly enter the separation efficiency (key figure 1) based on available information. In manure separation, often only results of analysis of the solid fraction (delivery notes) is available. Therefore, an alternative method can be used to determine separation efficiency, based on the following data about the solid fraction:

1. Amount of solid fraction removed (tons)
2. N content solid fraction (kg / ton)
3. P_2O_5 content solid fraction (kg / ton)

The above data can be used to determine what the separation efficiency has been, but only if the quantities of N and P produced in manure are known.

By default, the N and P_2O_5 contents of the incoming slurry are determined as described above. In practice, the slurry that is separated is not always the average manure present on the farm, sometimes just manure from a certain manure pit or from a certain animal group. Also in some cases the incoming manure is measured. That is why there is an option in ANCA to specify the composition of the incoming slurry. This alters the composition of the residual (not separated) slurry.

2.1.6 Manure digestion

During manure digestion part of the organic matter is converted into energy (methane and carbon dioxide). The fermented manure contains more mineral nitrogen, less organically bound nitrogen and less carbon.

Manure digestion affects:
1. Energy: production and use (see section 2.5)
2. Gaseous emissions during manure storage and manure application (see section 2.2)
3. Emission of methane from manure (see section 2.5)
4. Supply of effective organic matter (see section 2.5)

For manure digestion, the following information is requested:
1. Amount of manure entering the digester (tons)
2. Supply of co-substrates (quantity in tons, kg N and kg P_2O_5)

2.1.7 Criticical notes on BEX and manure production of other ruminants and non-ruminants

Use of constants as input for BEX

Input parameters for BEX that can hardly be determined in practice are entered as a constant in the BEX calculation method (an average value for the Netherlands). The combined effect of all constants used as input for BEX influences the accuracy of BEX results. In a scientific evaluation by the Dutch Committee of Experts on the Fertilizers Act (CDM) it was concluded that BEX is sufficiently accurate to be used for legal purposes (Šebek, 2008). This means that the currently used constants jointly result in a good estimate of the N and P excretion. Adjustment of individual constant parameters without taking into account interrelations will affect BEX accuracy.

For example, there is discussion about the constant used for VEM coverage in BEX (102% of the requirement). ANCA uses a VEM coverage percentage of 102%, which guarantees uniformity with other laws and regulations (Handreiking, 2019). However, in trials, a wide range of VEM coverage percentages is observed (roughly between 98% and 108%; and even above 110% in case of much illness (e.g. much mastitis) or poorly digestible rations). In practice, it is assumed that a VEM coverage of 105% better matches reality (especially with maize rations), but in practice it is seldom possible to determine VEM coverage. Due to cross-connections with other assumptions, a possible change of the assumed VEM coverage can only take place if this is accompanied by consistency checks on other constants. Examples of such constants are listed below:

List of constant input parameters in BEX
1. Average VEM herd coverage (102%).
2. Percentage of dry cows (on an annual basis) in the herd, calculated back to the calendar year, is 315 days of lactation and 50 days of dry period (CRV, 2015; -, 2016; -, 2017)) .

3. Live weight adult cow (Jersey, Jersey cross, and Other; 400, 525, and 650 kg respectively).
4. VEM requirement for young stock younger and older than 1 year (see section 2.1.2.10).
5. Extra energy requirement (VEM) for movement and growth (see Table 2.1.2).
6. Weight, N and P content in animals (fetus + adnexa, calf, heifer, first-lactation heifer, cow; see Table 2.1.4). With these assumed weights and contents, N and P retention in the herd is calculated.
7. Dairy herd replacement percentage (28%), to determine age structure of the herd and retention in growth of 1st and 2nd lactation cows.
8. The number of calves born per cow per calendar year (= 0.70), to calculate the retention in fetus + adnexa in dairy cattle.
9. The number of calves born per heifer per calendar year (= 0.79), to calculate the retention in fetus + adnexa in young stock.
10. P content in milk = 0.97 g / kg of milk. In Dutch monitoring project (Koeien & Kansen) P content varied from approximately 0.86 to 1.12 g P / kg milk. This standard value is used only if the farm-specific P content has not been measured by a certified institution.
11. VEM value of pasture grass from production grassland = 960 VEM / kg DM
12. VEM value of pasture grass of natural grassland = 860 VEM / kg DM

Comments

- It is not possible to determine the average composition (VEM, N and P content) of silages consisting of different feeds (mixed silage). Farms with mixed silages cannot participate in the BEX. Three exceptions are made. These apply when:
  - the mixed silage is homegrown, or if one of the products is purchased maize silage, provided that the feeding value and quantity have been determined for the individual silages and the purchased maize silage. Also silage losses due to adding a second-cut silage in the same pit must be accounted for.
  - 90% of the DM in the silage consists of the same roughage and the rest consists of an *unknown* purchased (moist) roughage.
  - 80% of the DM in the silage consists of the same roughage and the rest consists of a *known* purchased (moist) roughage.
- At farms that apply manure separation to a high degree, it is possible that the volume of manure specified in ANCA is not available. The manure volume on a farm is difficult to determine, which means that the calculated manure volume can deviate from what is actually present on a farm. Additives in the form of rinse water and rainwater play a role in this. Making different fertilizer flows and types more specific makes it more difficult to achieve a balanced fertilizer balance (in volume and contents), without revealing any unplausible results. For this reason, it is preferable to specify the amount of manure separation on the farm as a percentage of the total manure production.
- Problems may arise not only in the separation of manure, but also in the 'destination' of the various types of manure (import and export, stocks, application). Accurate input data / administration is required. However, despite accurate input, it can still lead to situations in which the outcome of the calculation model deviates too much from reality. For example, the actual export of manure may deviate from the outcome of the calculation model. Particularly in the case of farmer-farmer export, which mainly uses standard values, in reality less manure is sometimes exported than calculated in ANCA. Vice versa, if the actual contents are larger than the standard values, less manure remains on the farm than calculated. Imports of manure stocks are also often a 'weak link'. This can lead to unexpected results of the calculation model.

With regard to manure production by 'non-ruminants', the following should be noted. Since the most common non-ruminant livestock species kept on dairy farms are fattening pigs, sows, laying hens, broilers and white meat calves, only these ‘non-ruminant animal’ categories are included in ANCA. This means not all types of 'non-ruminants' are included in ANCA. For a more complete ANCA, more species of 'non-ruminants' should be included. This applies, for example, to pigs other than fattening pigs and breeding sows.

In order to limit the amount of data entry in ANCA, the (net) manure production of the non ruminants (in N and P_2O_5) can be obtained from the (legal) Fertilization Plan, together with the export and stock balance of manure of non-ruminants. In this way, the correct amounts of nitrogen and phosphate are used, with a limited number of input parameters. In this way, imports of nitrogen and phosphate with feed and animals and exports of nitrogen and phosphate with animals are not required. However, this does mean that the utilization of nitrogen and phosphate by 'non-ruminants', and of these types of farms as a whole, cannot be calculated by the KringloopWijzer.

2.2 Farm-specific Ammonia Emission (BEA)

2.2.1 Introduction

BEA is a calculation tool for calculating the 'Farm-specific Ammonia Emission'. The calculated losses relate to the ammonia-N (NH_3-N) that is released from stables, from manure storages, from feces and urine that are excreted during grazing, from machine-spread animal manure on grassland and arable land (arable roughage crops such as silage maize and exported arable crops) and from some types of synthetic fertilizers. In addition, there are a number of other NH_3 emission sources (standing, grazed and harvested crops) that are also discussed in this part of the ANCA calculation rules.

BEA uses the National Emission Model for Ammonia to calculate NH_3 emissions (NEMA, Van Bruggen *et al.* , 2017; -, 2018). This method makes an inventory of N flows in manure, i.e.: herd excretion, housing (barn floor and manure storage under the barn), storage outside the barn and manure application. The share of ammonia nitrogen in the total amount of nitrogen (% TAN) plays an important role in this.

At each step, emission factors (EF) are used to calculate how much TAN volatilizes as ammonia (NH_3-N) and other gaseous N compounds. EF's are based on the results of scientific research and described by van Bruggen *et al.* (2017), and connect wherever possible with existing Dutch legislation. For example, the EF's for the stable (floor and storage) are based on the NH_3 emissions measurements that are the basis of the Directive Ammonia and Livestock (RAV, http://wetten.overheid.nl/BWBR0013629/geldigheidsdatum_09-12- 2013). In principle, the BEA therefore also corresponds with the RAV. The way in which the losses are calculated and expressed do differ. The RAV is based on the relationship between the emission of ammonia and the concentration of ammonium in manure and urine. NEMA and BEA, however, are based on the relationship between ammonia emission and the amount of TAN excreted. The RAV expresses the emission in kg of ammonia per animal place per year, while BEA expresses the emission in kg of ammonia per farm.

The BEA uses the BEX to calculate the amount of N and TAN excreted by the dairy cattle (the source of ammonia emissions). However, there are additional calculation rules in the BEA and these relate to the conversion from N excretion (= output BEX) to TAN excretion. It is a relatively small addition to the BEX and that addition is described in section 2.2.2.

2.2.2 Calculation method

2.2.2.1 General

The N and TAN excretion (the emission source) depends on the composition, production and feeding of the livestock and the volatilization of that TAN (ammonia losses and other gaseous N losses), in terms of the emission from the stable, depends on the housing design and manure storage in the stable. With regard to the dairy herd, these factors are taken into account in the ANCA tool. With regard to the emissions from the housing of 'other ruminants' and 'non-ruminants', however, ANCA assumes fixed ration-independent values per animal place (see sections 2.2.2.2 and 2.2.2.3). Part of the manure is stored in a manure storage outside the stable (external manure storage), from which ammonia losses also occur. Ammonia emission also takes place when manure is applied to land. This part of the emission depends on the land use and the way in which animal manure is spread. In addition, the type of synthetic fertilizer also plays a role. The calculation procedure for the BEA for specialized dairy farms is shown schematically in Figure 2.2.1.

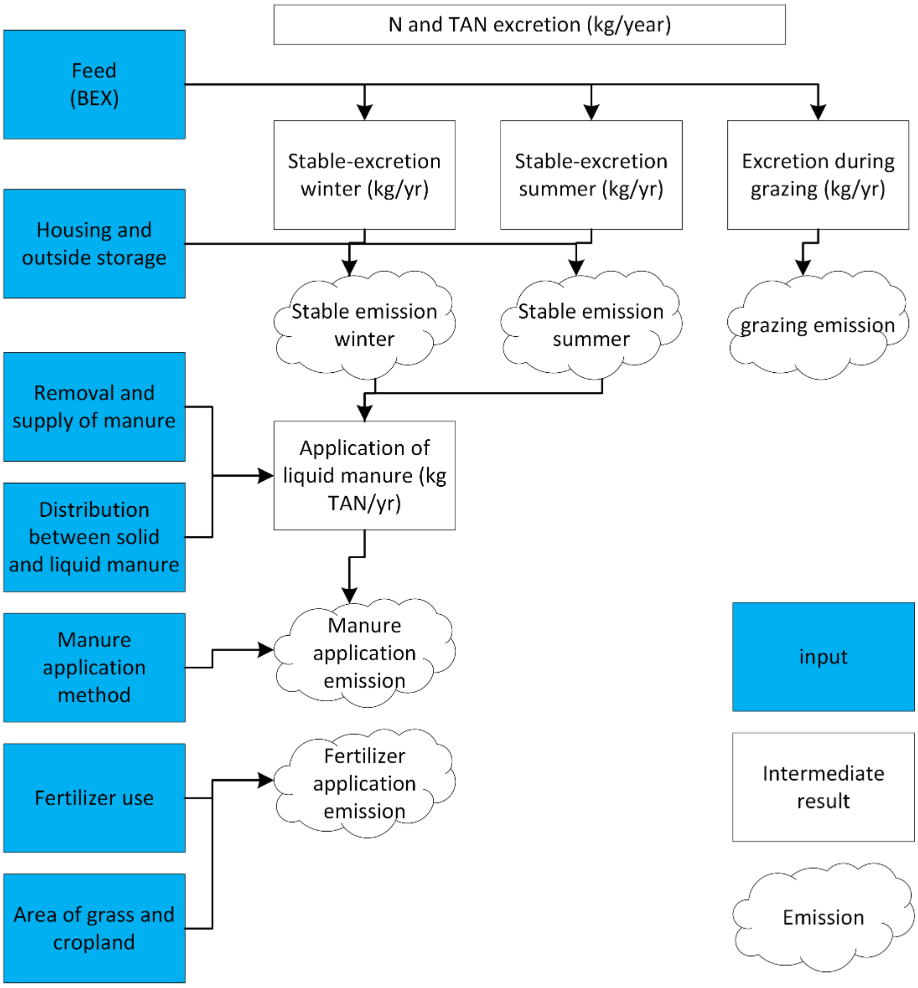

Figure 2.2.1 *Schematic representation of the calculation of the ammonia emissions (kg NH_3 per year) of a dairy farm.*

BEA requires information on:

With regard to 'dairy cattle' (dairy cows and associated young stock)

- Proportion of slurry in cows, heifers and calves.
- The amount of N and TAN produced by the livestock (TAN excretion in kg / year).
- The distribution of the N and TAN excretion (kg/year) over the housing period (in summer and in winter) and the grazing period.
- The amount of mineral N (kg / year) formed by mineralization in the manure storage (slurry).
- The amount of organic N (kg / year) formed by immobilization in the manure storage (solid manure).
- The amount of TAN (kg / year) that is imported or exported with manure.

As for 'other ruminants'

- The numbers of animals present on average per animal category.
- The nature of the animal manure (proportion of slurry).

As for 'non-ruminants'

- The average number of animals present per animal category.
- The nature of the animal manure (proportion of slurry).
- House type (predefined types based on Dutch housing system categories and ammonia emission factors; 'RAV')
- Data that can be directly derived from the (legal) fertilization plan with the net excretion of non ruminants.

With regard to 'dairy cattle', 'other ruminants' and 'non-ruminants' together

- The distribution of TAN for application on grass or arable land, including the application method.
- The amount of synthetic fertilizer applied on grass or arable land.

Emission factors (EF and mineralization coefficient, from NEMA)

- EF ammonia for the barn of dairy cattle during the housing period (in percentage of TAN production).
- EF ammonia for the barn of dairy cattle in the grazing period (in percentage of TAN production).
- EF ammonia for manure excreted on pasture by dairy cattle (in percentage of TAN excretion).
- EF ammonia for external manure storage (in percentage of stored N).
- EF other N-gases for the barn of dairy cattle (in percentage of N-excretion).
- Mineralization coefficient for organically bound N in the barn storage of dairy cattle.
- Immobilization coefficient for mineral N in the manure storage of dairy cattle.
- EF for application of manure for grass and arable land and for manure application method.
- EF for application of synthetic fertilizer, per type of fertilizer.

The following sections describe how the information related to the amounts of TAN mentioned above are calculated.

2.2.2.2 N-excretion and TAN production by livestock

2.2.2.2.1 Dairy herd including young stock

The BEA is based on the gross N excretion from the BEX, so the N excretion under the tail of the cow (for conversion to the final net BEX excretion). However, the BEA calculates the ammonia emissions in the barn based on the amount of TAN (mineral N) in the manure, per animal group. Therefore, a correct estimate of the TAN excretion is necessary. This requires information about the feed materials used and the digestion coefficient of the crude protein (DCCP) in those feed materials per animal group. The DCCP is used to calculate which part of the N excretion is excreted in the urine. The urinary part of the N-excretion is in principle volatile (TAN). The other N is excreted in faeces and only becomes TAN when there is mineralization (in the manure storage).

In order to determine the gaseous nitrogen losses from the manure (faeces and urine) of the dairy cattle, the different feed categories that have been fed to the dairy cattle (being dairy cows and associated young stock) must first be allocated to the different categories of young stock and dairy cows. The starting point is the VEM requirement of an animal category (which is equal to the total VEM intake of this animal category: see section 2.1.2.10).

First of all, a certain allocation of feed categories applies for young stock. This allocation always concerns the amount of feed (in kVEM) that is provided to the dairy herd, in case there are other ruminants (Table 2.1.3). Allocation takes place in accordance with the methodology of the Dutch Working Group Standardization of Manure Figures (WUM) and is as follows for young stock:

- Artificial milk powder: all imported milk powder, not intended for other ruminants, is allocated to calves:

- Fresh grass calves and heifers: calculated based on the number of pasture days and the ratio of the amounts of fresh grass, grass silage and silage maize silage fed (see section 2.1.2.12);
- Concentrate feed: the share of the VEM requirement from concentrates is 25% for the calves in the stable and 10% in the pasture, and for heifers 5% in the stable and 0% in the pasture.
- Roughage: calves in the barn receive 75% of the VEM requirement in fodder from grass silage and 25% from maize silage, and heifers 90% from silage silage and 10% from maize silage. The VEM requirement in the stable of both calves and heifers is equal to the total VEM requirement minus the VEM intake from milk powder, concentrates and fresh grass.

The above principle applies for allocation of feed categories to young stock. If a certain feed category appears to be missing or there is too little of it, the following is applied:

- Allocated first to calves and then to heifers;
- The amounts of milk powder and fresh grass are fixed; these are listed in the administration, and have been calculated, respectively. However, the latter may increase as shown in the following. If extra fresh grass is allocated to the calves or the heifers, this is at the expense of the calculated amount of fresh grass allocated to the dairy cows;
- Concentrate feed: with no or insufficient concentrate feed, the required VEM requirement from concentrate feed is supplemented from (in this order): other products, maize silage, grass products, fresh grass;
- Maize silage: with no or insufficient maize silage, the VEM requirement from maize silage is supplemented from (in this order): grass products, other products, concentrates, fresh grass;
- Grass products (grass silage): with no or insufficient grass products, the VEM requirement from grass products is supplemented from (in this order): silage maize silage, other products, concentrates, fresh grass.

It is then possible to calculate what can be allocated to the dairy cows. The following applies per feed category:

VEM intake_milkcow = VEM intake_total - VEM intake_calves - VEM intake_heifers

When feed categories (with various feed types) are allocated to young stock and dairy cattle, these quantities represent the feed intake of these animal categories in a year. The average daily ration can then be calculated by dividing by the number of days per year. This average daily ration is the starting point for the calculations of the gaseous N-losses for all days in the year. Although this may not be entirely correct, it is expected to be a fairly accurate approach to reality, and in accordance with the way in which the NEMA working group calculates annual rations.

The information about the type and quantity of the feed materials used and the gross N excretion of the three animal categories (dairy cows, heifers, calves) forms the basis for the final BEX (section 2.1). The BEX calculates the gross N excretion as follows:

N-excretion 'under the tail' (kg) = N intake (kg) - N retention (kg)

The '*under the tail'* N-excretion consists of faeces and urine. In addition to the information from BEX, information about the DCCP of the feed materials used is required to calculate the distribution of the N-excretion between the faeces and the urine.

The distribution of the N-excretion between faeces and urine is calculated by BEA as:

N-excretion_feces (kg) = N-intake (kg) x [1 - DCCP (g VRE / g RE) x 0.91]

N excretion_urine (kg) = [N intake (kg) x DCCP (g VRE / g RE) x 0.91] - N retention (kg)

The calculated N-excretion_urine is equated with TAN excretion (in accordance with NEMA).

TAN excretion (kg) = N excretion urine (kg)

The factor 0.91 in the above formulas is taken from Bannink *et al.* (2018).
An additional source of TAN is mineralization of organically bound N. For slurry, in accordance with NEMA and for average Dutch conditions (climate and housing system), it is assumed that 10% of the non-ammoniacal N (= organic N) in the barn and the manure storage in that barn is converted into TAN.

N mineralization (kg) = [N excretion under the tail (kg) - TAN excretion (kg)] x proportion slurry x 0.1

In case of solid manure, part of the mineral N is converted into organic N. In accordance with NEMA, it is assumed that for solid manure, under average Dutch conditions (climate and housing system), 25% of the ammoniacal N (= mineral N) in the barn and manure storage in the barn is converted into non-ammoniacal N (= organic N). This is a net immobilization.

N-immobilisation (kg) = TAN excretion under the tail (kg) x proportion solid manure x 0.25

Total TAN production inside the barn is calculated as follows:

TAN barn (kg) = TAN excretion (kg) + N mineralization (kg) - N immobilization (kg)

Calculation of digestibility of crude protein
The DCCP (digestibility coefficient of crude protein) of feed materials is not known to the dairy farmer, but is calculated using regression equations from the Centraal Veevoederbureau (CVB, 2006, 2018). These equations estimate the digestible protein based on its chemical composition (total crude protein (CP), crude ash (CA) and, in the case of whole-ear corn silage (WECS), also crude fiber). For products with little variation, an average DCCP from the Animal Feed Table is used (CVB, 2011). The following categories of feed materials are distinguished in BEA:

1. Category 'grass silage' (contents per kg DM)

DCCP grass silage = (0.931 x CP - 43.2) / CP

2. Category 'grass hay' (contents per kg ds)

DCCP grass hay = (0.931 x CP - 43.2) / CP

3. Category 'grass meal / grass pellets / grass bales' (artificially dried) (contents per kg ds)

DCCP grass chunks = (0.878 x CP - 38.4) / CP

4. Category 'maize silage' (contents per kg ds)

DCCP maize silage = (0.969 x CP + 0.04 x CA - 40) / CP

5. Category 'grazed grass' (contents per kg ds)
The composition of fresh grass is not known for practical farms. In the BEX, the N / VEM ratio in fresh grass is calculated based on existing grass silage (see section 2.1.2.15). CP fresh grass = N / VEM fresh grass * 960 * 6.25.

DCCP meadow grass = (0.963 x CP -38.3) / CP

6. Category ‘compound feed’ For compound feed, insufficient information is available on practical farms to determine the DCCP. The relationship between the DCCP and the CP content has been established for a wide range of compound feeds:

DCCP = 54.66 + 0.084 x CP compound feed

7. Category ‘other feed’
Formulas are not available for all products. When a formula is missing, a fixed DCCP is used (Appendix 1).

2.2.2.2.2 Other ruminants
TAN production for the 'other ruminants' is calculated by dividing the net manure-N production (Table 2.1.6) into a part that is excreted indoors and a part that is excreted during grazing. These quantities are then converted to gross manure-N productions based on the net/gross ratio (Table 2.2.1). Finally, using the TAN proportions of manure excreted indoors and on pasture (Table 2.2.1), the quantities of TAN produced are calculated according to:

TAN production = net N excretion / (net / gross ratio) *% TAN / 100

Table 2.2.1. *Ratio to convert the net excretion of the manure N produced by 'other ruminants' into gross excretion and then convert these quantities into the amount of ammoniacal N (TAN).*

Category	Net/gross slurry ratio	Net/gross excretion ratio of solid manure	TAN-% of manure in stable	TAN-% of manure in pasture
Breeding bulls> 1 year (cat. 104)	0.894	0.894	62	62
Pasture and suckler cows (cat. 120)	0.973	0.972	61	61
Nursing calves, rosé or red meat (cat. 115)	0.851	0.851	60	60
Rosé calves, 3 months - slaughter (cat. 116)	0.851	0.851	60	60
Rosé calves, 2 weeks - slaughter (cat. 117)	0.857	0.857	53	53
Red meat bulls, 3 months - slaughter (cat. 122)	0.882	0.801	57	57
Breeding sheep (cat. 550)	0.915	0.915	57	72
Meat sheep, <4 months (cat. 551)	0.918	0.918	57	72
Other sheep,> 4 months (cat. 552)	0.915	0.915	57	72
Milk goats (cat. 600)	0.838	0.838	61	61
Rearing and meat goats, <4 months (cat. 601)	0.841	0.841	61	61
Rearing and meat goats,> 4 months (cat. 602)	0.838	0.838	61	61
Ponies (cat. 941)	0.913	0.913	74	78
Horses (cat. 943)	0.916	0.916	73	75

2.2.2.2.3 Non-ruminants
The ammonia emission from housing and storage of non-ruminants is not calculated as the product of the gross N excretion, TAN percentage and the emission factor, but as ammonia loss per animal place (Table 2.2.8).

2.2.2.3 TAN excretion in stable and pasture by livestock

2.2.2.3.1 Dairy herd

For the TAN excretion calculation, a distinction is made between the stable and pasture period because the EF for manure in the stable and storage is considerably higher than the EF for manure deposited on pasture. This is related to the effect of joint (stable) or separate (pasture) collection of dung and urine.

The distribution of the TAN excretion (kg / year) over the stable and pasture in the summer is based on the hours animals spend on pasture. It is assumed that the same amount of manure is produced during one hour of grazing as during an hour in the stable and that the amount of TAN in the manure does not vary during the day. This means that when the dairy herd is pastured 10 hours per day, 10/24 of the TAN is excreted on pasture and 14/24 in the stable. This approach differs from NEMA and RAV, in which only a distinction is made between zero-grazing, limited grazing and unlimited grazing.

2.2.2.3.2 Other ruminants

The distribution of the manure N and (associated) TAN excretion (Table 2.2.1) over the stable and pasture is based on the days the animals spend on pasture. The days on pasture are estimated based on the VEM intake from fresh grass in 'other ruminants', assuming animals graze all day.

Days on pasture = VEM intake from grass / VEM intake total * 365

2.2.2.4 Ammonia loss and other gaseous N losses from housing

2.2.2.4.1 Dairy herd

NEMA provides a combined EF for the ammonia emission from the stable (from the floor and the manure storage pit). This EF is therefore called 'N losses from stable and storage' and the BEA calculates with this EF. The EF for TAN in the stable and storage represent the percentage of volatilization of the total amount of TAN in the stable and storage during a calendar year. The TAN and N excretion on pasture is not included. The TAN in stable and storage concerns the sum of:

- TAN excretion of dairy herd in the stable in the winter period (= 100% of the TAN excretion in that period).
- TAN excretion of dairy herd in the stable in the summer period (% of the TAN excretion in that period depends on grazing time).
- Mineralization of the organically bound slurry-N in the storage (= 10% of the N-excretion of the dairy herd in the stable during the housing period + the period on pasture).
- Immobilization of mineral N in solid manure in storage of 25%.

Part of the TAN is lost through volatilization as ammonia and part through volatilization in other gaseous N losses. The latter concerns nitrogen oxides (N_2O and NO) or elemental nitrogen (N_2). The EF indicates which part of the TAN is lost, which depends on the stable or pasture period, the type of manure (solid manure or slurry) and the type of stable. NEMA (Van Bruggen *et al.*, 2017) makes a distinction between barns with slatted floors and low-emission stables. ANCA calculates the emissions for a standard barn (Tables 2.2.2 and 2.2.3) and any emission reduction is calculated via the selected RAV barn (see other part of this section).

Table 2.2.2 *The gaseous emissions of NH_3 -N and other N in a standard barn for dairy cows according to NEMA (Van Bruggen et al., 2017).*

Season	Fertilizer type	EF NH3-N (as% of TAN)		EF other N (as% of N-total)	
		Dairy cow	Young cattle	Dairy cow	Young cattle
Stable period	Slurry	14.3	14.3	2.4	2.4
	Solid manure	14.3	14.3	3.5	3.5
Grazing period	Slurry	14.3-40.9 (see Table 2.2.3)		2.4	2.4
	Solid manure	14.3-40.9 (see Table 2.2.3)		3.5	3.5

Table 2.2.3 *The emissions from the barn by dairy cattle during the summer period of NH_3N depending on the number of hours of outdoor grazing.*

Hours of outdoor grazing per day	Emission factor (kg NH_3 per 100 kg excreted ammonium N)
0	*14.3*
1	*14.5*
2	*14.8*
3	*15*
4	*15.3*
5	*15.7*
6	*16*
7	*16.5*
8	*16.9*
9	*17.5*
10	*18.1*
11	*18.8*
12	*19.6*
13	*20.6*
14	*21.7*
15	*23.2*
16	*24.9*
17	*27.2*
18	*30.3*
19	*35.5*
20	*40.9*

The EF in Tables 2.2.2 and 2.2.3 can be used for practical farms, but these barn types only apply for part of the farms. In the Ammonia and Animal Husbandry Regulation (RAV), 30 barn types are distinguished for the category of dairy cattle (Table 2.2.5), each with their specific emission factors. The RAV emissions are expressed as kg NH_3 per animal place per year and are therefore not readily applicable in BEA (see section 2.2.1), in which emission factors are expressed as a fraction of the ammonia produced. This means that an emission factor per RAV house type is needed for the BEA -calculations of stable emissions. These emission factors are not available and are therefore generated in the BEA by relating the emission of each RAV housing type to the emission of the standard RAV housing type 'A1.100 - other housing systems'. It is assumed that the emission according to RAV stable A1.100 corresponds to the emission as calculated according to the NEMA method of the 'low-emission stable'. For the other RAV housing types, the calculated stable emission is then multiplied by a housing type correction factor (see Table 2.2.5), which corresponds to the ratio between the RAV emission per animal place of the housing type and the RAV emission per animal place of stable type 'A 1.100 - other housing systems’. Table 2.2.4 shows an example of this.

Table 2.2.4 *Example comparison RAV stable A1.5 with reference RAV stable A1.100.*

RAV-Stable	Emission factor (kg NH_3 per animal place per year)	Correction factor relative to A1.100
A 1.100 (standard)	13	
A 1.5	11.8	11.8 / 13 = 0.91

BEA first calculates the NH_3 emissions from the stable and storage as if it were the standard RAV housing type A1.100. If another housing type is chosen (e.g. A1.5), the standard calculated NH_3 emission from the stable and storage is multiplied by the correction factor for the housing type (so for housing type A1.5 by 0.91).

Table 2.2.5 *Correction factors for the calculated emission of NH_3 -N depending on the type of housing (source barn types: Kenniscentrum Infomil).*

Code	Category	NH_3 [1)]	Factor [2)]
A 1	Animal category of cows older than 2 years		
A 1.100	Standard stable	13	1
A 1.1	Tiestall with slurry	5.7	0.44
A 1.2	Loose housing - slatted floor, flushing system or sloping floor, slurry gutter, flushing system	10.2	0.78
A 1.3	Loose housing - sloping floor, slurry gutter	10.2	0.78
A 1.4	Loose housing - sloping floor, flushing system	9.2	0.71
A 1.5	Loose housing - grooved floor, manure scraper	11.8	0.91
A 1.6	Free stall barn - solid sloping floor, profile, manure scraper	11	0.85
A 1.7	Free stall barn - solid sloping floor, rubber top layer, manure scraper	11	0.85
A 1.8	Free stall barn – grooved floor, studs, manure scraper	11.8	0.91
A 1.9	Free stall barn - slatted floor, convex rubber top layer, sealing flaps in slots	6	0.46
A 1.10	Free stall barn - slatted floor, convex rubber top layer	7	0.54
A 1.11	Free stall barn - flat floor, profile, sloping slots, finger scraper	11.8	0.91
A 1.12	Free stall barn - flat floor, profile, sloping slots, manure scraper	12.2	0.94
A 1.13	Free stall barn - slatted floor, cassettes in slots	7	0.54
A 1.14	Free stall barn - flat floor, profile, sloping slots, manure scraper, roof insulation	7	0.54
A 1.15	Free stall barn - flat floor, profile, sloping slots, finger scraper	10.3	0.79
A 1.16	Free stall barn - V-floor of mastic asphalt, slurry discharge pipe	11.7	0.9
A 1.17	Mechanically ventilated stable, chemical air scrubber	5.1	1 [3)]
A 1.18	Free stall barn - V-floor, profile, slurry discharge pipe	8	0.62
A 1.19	Free stall barn - slatted floor, sloping slots, sealing flaps in slots	11	0.85
A 1.20	Free stall barn - floor, perforations and sloping profiling, manure scraper	10.1	0.78
A 1.21	Free stall barn - floor, sloping longitudinal grooves, V-shaped transverse grooves, manure scraper	7	0.54
A 1.22	Free stall barn - grooved floor, slatted floor, rubber top layer and sealing flaps in waiting area and passages	11	0.85
A 1.23	Free stall barn - floor slabs, profile, sloping longitudinal slots, transverse grooves, manure scraper	6	0.46
A 1.24	Free stall barn - floor, sloping longitudinal slots, perforations, manure scraper	9.1	0.7
A 1.25	Free stall barn - flat floor, rubber mats, sloping profile	10.3	0.79
A 1.26	Free stall barn - V-floor, rubber mats, profile, slurry gutter, manure scraper	8	0.62
A 1.27	Free stall barn - slatted floor, sealing flaps, sloping grooves, manure scraper, misting system	8	0.62
A 1.28	Free stall barn - slatted floor, rubber mats, composite lugs, sealing flaps in slots, manure scraper	6	0.46
A 1.29	Free stall barn - profiled sloping floor, cavities, manure scraper	9.9	0.76
A 1.30	Free stall barn - convex rubber mats, about 7% slope, concrete grids	9.4	0.72

Code	Category	NH_3 [1)]	Factor [2)]
A 1.31	Free stall barn - grooved floor, closed sloping floor with profiled rubber tiles, manure scraper	8.1	0.62
A 1.32	Free stall barn - flat concrete floor slabs, slots, profile, sloping grooves, slurry gutter with slurry holes, manure removal	9.1	0.7
A 1.33	Free stall barn - flat floor, rubber slots, sloping longitudinal slots, profiled rubber with grooves and studs, manure scraper	7.1	0.55
A 1.34	Free stall barn - solid grooved floor, rubber mats, sloping profile, composite cams, finger scraper	9	0.69
A 1.35	Free stall barn - flat floor, rubber slots, sloping longitudinal slots, profiled rubber with grooves and studs, finger scraper	8.3	0.64

Code	Category	NH_3 [1)]	Factor [2)]
A 1.100	Other housing systems	13	1
A 1.100 organic deep littter	Organic – deep litter system with solid manure	13	1
A 1.100 organic tiestall	Organic – tiestall with solid manure	13	1
A 1.100 other organic	Organic - other housing systems for dairy cows	13	1

[1)] Emission in kg NH_3 per animal place per year according to the RAV (ammonia and animal husbandry Regulation).

[2)] Barn type correction factor for the calculated emission of NH_3 -N compared to barn type A1.100.

[3)] RAV-Stable A 1.17 is a house with an air scrubber. NH3 emission is reduced, but the reduced gaseous N-loss is no longer present in the animal manure, but is contained in the waste water of the air scrubber. The correction factor for this house is therefore 1.

The emission of NH_3 -N from housing (kg N) is therefore equal to:

$$NH_3\text{-}N_{housing} = RAV_{correction} \times$$

$$((TAN\ production\ in\ stable_{winter} \times EF\ NH_3\text{-}N\ standard\ stable_{winter}) +$$

$$(TAN\ production\ in\ stable_{summer} \times EF\ NH_3\text{-}N\ standard\ stable_{summer}))$$

If the young stock are housed in the same stable as the dairy cattle, the ammonia emissions from young cattle are reduced by the same factor as the dairy cattle.

The emission of N-other from housing (kg N) is therefore equal to:

$$N\text{-}other = (N\text{-}excretion\ in\ stable_{winter} \times EF\ N\text{-}other\ standard\ stable_{winter}) + (N\text{-}excretion\ in\ stable_{summer} \times EF\ N\text{-}other\ standard\ stable_{summer})$$

2.2.2.4.2 Other ruminants

By combining the calculated TAN produced by ‘other ruminants’ (section 2.2.2.2.2) during the housing period and the emission factors for ammonia-N during the housing period (Table 2.2.6), the ammonia emissions from the housing can be calculated (NH_3 - N_{stable}). The indicated table also shows the emission factors for the other gaseous N losses ($N\text{-}other_{stable}$). Both types of losses are needed to calculate how much N on balance goes to an external manure storage or directly to the field. Calculation rules are:

$$NH_3\text{-}N_{stable} = TAN\ production\ total * (365 - number\ of\ days\ on\ pasture) / 365 * EF\ NH_3$$

$$N\text{-}other_{stable} = Gross\ N\text{-}excretion\ total * (365 - number\ of\ days\ on\ pasture) / 365 * EF\ N\text{-}other$$

Table 2.2.6 *Emission factors (EF) for ammonia-N and other gaseous losses per category 'other ruminants' per individual fertilizer (SL = slurry, SM = solid manure).*

category	Fertilizer type	EF NH_3-N (% of TAN production)	EF N-Other (% of gross N excretion)
Breeding bulls> 1 year (cat. 104)	SL	14.3	2.4
	SM	14.3	3.5
Pasture and suckler cows (cat. 120)	SL	14.3	2.4
	SM	14.3	3.5
Nursing calves, rosé or red meat (cat. 115)	SL	12.7	2.4
	SM	12.7	3.5
Rosé calves, 3 months - slaughter (cat. 116)	SL	20.5	2.4
	SM	20.5	3.5
Rosé calves, 2 weeks - slaughter (cat. 117)	SL	22.9	2.4
	SM	22.9	3.5
Red meat bulls, 3 months - slaughter (cat. 122)	SL	12.7	2.4
	SM	12.7	3.5
Breeding sheep (cat. 550)	SL	27.8	2.4
	SM	27.8	3.5
Meat sheep, <4 months (cat. 551)	SL	27.8	2.4
	SM	27.8	3.5
Other sheep,> 4 months (cat. 552)	SL	27.8	2.4
	SM	27.8	3.5
Milk goats (cat. 600)	SL	17.1	2.4
	SM	17.1	3.5
Rearing and meat goats, <4 months (cat. 601)	SL	17.1	2.4
	SM	17.1	3.5
Rearing and meat goats,> 4 months (cat. 602)	SL	17.1	2.4
	SM	17.1	3.5
Ponies (cat. 941)	SL	29.0	2.4
	SM	29.0	3.5
Horses (cat. 943)	SL	19.5	2.4
	SM	19.5	3.5

2.2.2.4.3 Non-ruminants

Standard ammonia emissions are used for 'non-ruminants', which are independent of ration composition. These depend on the animal type and the stable type, using the equation:

Ammonia emission (kg NH_3–N) = ANA / (stocking density / 100) x 14/17 x ammonia (kg NH_3 / animal place)

where:

ANA = average number of animals present (from the input data)
Stocking density = standard stock density (Table 2.2.7)
Ammonia = emission per animal place (Table 2.2.8)

Table 2.2.7 *Standard stocking density for non-ruminants.*

Animal species	Stocking density (%)
Farrowing sows	89
Dry and pregant sows	97
Weaned piglets	91
Fattening pigs	97
Laying hens	96
Broilers	82
White meat calves	93

Table 2.2.8 *Ammonia emissions per animal place for different types of non-ruminants and housing systems.*

Animal species	Rav code	Description	Ammonia (kg NH_3 / place)
Laying hens	E 2.5.6	Colony housing - aeration via manure belt	0.030
	E 2.7	Floor system - approx 1/3 litter floor + 2/3 slatted floor	0.315
	E 2.8	Floor system - aeration via Perfosystem	0.110
	E 2.9.1	Floor system - aeration under the slatted floor	0.125
	E 2.9.2	Floor system - aeration via tubes on both sides of nests	0.150
	E 2.9.3	Floor system - aeration via vertical ventilation shafts	0.150
	E 2.10	Housing – acid air scrubber, 90% NH_3 reduction	0.032
	E 2.11.1	Aviary housing - 50% slatted floor and manure removal by belt system once a week	0.090
	E 2.11.2	Aviary housing - 50% slatted floor and manure removal by belt system twice a week	0.055
	E 2.11.3	Aviary housing - 30-45% slatted floor and aeration via manure belt	0.025
	E 2.11.4	Aviary housing - 55-60% slatted floor and aeration via manure belt	0.037
	E 2.12.1	Free-range housing - 2 floors high	0.068
	E 2.12.2	Free-range housing - frequent manure / litter removal	0.106
	E 2.13	Housing - biological air scrubber, 70% NH_3 reduction	0.095
	E 2.14	Housing - biofilter, 70% NH3 reduction	0.095
	E 2.15	Housing – acid air scrubber, 70% NH_3 reduction	0.095
	E 2.100	Other housing systems	0.315
Broilers	E 5.1	Plenum floor	0.005
	E 5.2	Perforated floor	0.014
	E 5.3	Tiered system slatted floor	0.005
	E 5.4	Acid air scrubber - 90% NH_3 reduction	0.008
	E 5.5	Heated and cooled littered floor	0.045
	E 5.6	Mixed air ventilation	0.037
	E 5.7	Biological air scrubber - 70% NH_3 reduction	0.024
	E 5.8	Tiered system - manure belt	0.020
	E 5.9.1.2.2	Separate hatching and growing - mixed air ventilation	0.033
	E 5.9.1.2.4	Separate hatching and growing - hot water heaters and fans	0.030
	E 5.10	Heating based on heaters and fans	0.035
	E 5.11	Air mixing system in combination with heat exchanger	0.021
	E 5.12	Biofilter - 70% NH_3 reduction	0.024
	E 5.13	Acid air scrubber - 70% NH_3 reduction	0.024
	E 5.14	Heaters - air mixing system	0.035

Animal species	Rav code	Description	Ammonia (kg NH_3 / place)
	E 5.15	House with tube heating	0.012
	E 5,100	Other housing systems	0.080
Farrowing sows	D 1.2.1	Slurry flushing system in gutters	3,300
	D 1.2.2	Plastic collection floor on top of manure pit	3,700
	D 1.2.3	Coated underneath slats with manure scraper (e.g. rack and pinion)	4,000
	D 1.2.4	Manure scraper	3,100
	D 1.2.5	Manure gutter	3,200
	D 1.2.6	Manure channel and water channel	4,000
	D 1.2.7	Sloped floor underneath slats	5,000
	D 1.2.8	Manure collection in acidified liquid fraction	3,100
	D 1.2.9	Scraper in manure gutter	2,500
	D 1.2.10	Biological air scrubber - 70% NH_3 reduction	2,500
	D 1.2.11	Acid air scrubber - 70% NH_3 reduction	2,500
	D 1.2.12	Manure cooling system	2,400
	D 1.2.13	Manure tray	2,900
	D 1.2.14	Manure tray with water channel and manure channel	2,900
	D 1.2.15	Acid air scrubber - 95% NH_3 reduction	0.420
	D 1.2.16	Water channel	2,900
	D 1.2.17.1	Combi scrubber (acid) - 85% NH_3 reduction	1,300
	D 1.2.17.2	Combi scrubber (biological) - 70% NH_3 reduction	2,500
	D 1.2.17.3	Combi scrubber (acid) - 85% NH_3 reduction	1,250
	D 1.2.17.4	Combi scrubber (biological) - 85% NH_3 reduction	1,250
	D 1.2.17.5	Combi scrubber (biological) - 85% NH_3 reduction	1,300
	D 1.2.17.6	Combi scrubber (biological) - 90% NH_3 reduction	0.830
	D 1.2.18	Biological air scrubber - 80% NH_3 reduction	1,660
	D 1.2.19	Acid air scrubber - 90% NH_3 reduction	0.830
	D 1.2.20	Manure tray with water channel and manure channel, cooling system	1,300
	D 4.1	Floating balls in the manure	5,890
	D 1.2.100	Other housing systems	8,300
Other sows	D 1.3.1	Triangular metal slats	2,400
	D 1.3.2	Manure gutter with combined slats	1,800
	D 1.3.3	Flushing gutters	2,500
	D 1.3.4	Manure collection in acidified liquid fraction	1,800
	D 1.3.5	Manure scraper	2,200
	D 1.3.6	Biological air scrubber - 70% NH_3 reduction	1,300
	D 1.3.7	Acid air scrubber - 70% NH_3 reduction	1,300
	D 1.3.8	Manure cooling system	2,200
	D 1.3.9.1	Feeding crates or automatic sow feeder with triangular metal slats	2,300
	D 1.3.9.2	Feeding crates or automatic sow feeder with slats other than metal triangular	2,500
	D 1.3.10	Walking house	2,600
	D 1.3.11	Acid air scrubber - 95% NH_3 reduction	0.210
	D 1.3.12.1	Combi scrubber (acid) - 85% NH_3 reduction	0.630

Animal species	Rav code	Description	Ammonia (kg NH_3 / place)
	D 1.3.12.2	Combi scrubber (biological) - 70% NH_3 reduction	1,300
	D 1.3.12.3	Combi scrubber (acid) - 85% NH_3 reduction	0.630
	D 1.3.12.4	Combi scrubber (biological) - 85% NH_3 reduction	0.630
	D 1.3.12.5	Combi scrubber (biological) - 85% NH_3 reduction	0.630
	D 1.3.12.6	Combi scrubber (biological) - 90% NH_3 reduction	0.420
	D 1.3.13	Biological air scrubber - 80% NH_3 reduction	0.630
	D 1.3.14	Acid air scrubber - 90% NH_3 reduction	0.420
	D 1.3.15	Separate discharge of manure and urine, V-shaped manure belt, metal triangular slats	2,200
	D 4.1	Floating balls in the manure	3,000
	D 1.3.100	Other housing systems	4,200
Belt buckle. Piglets	D 1.1.1	Coated floor with manure scraper (e.g. rack and pinion drive)	0.200
	D 1.1.2	Flushing gutter system	0.250
	D 1.1.3	Manure collection in water	0.150
	D 1.1.4.1	Water and manure channel 0.13 m^2 per piglet	0.260
	D 1.1.4.2	Water and manure channel 0.19 m^2 per piglet	0.330
	D 1.1.5	Partly slatted, max 60% slatted	0.390
	D 1.1.6	Manure collection in acidified liquid, fully slatted	0.180
	D 1.1.7	Manure collection in acidified liquid, partly slatted	0.250
	D 1.1.8	Sloping manure belt	0.230
	D 1.1.9	Biological air scrubber - 70% NH_3 reduction	0.210
	D 1.1.10	Acid air scrubber - 70% NH_3 reduction	0.210
	D 1.1.11	Manure cooling system, partly slatted	0.170
	D 1.1.11	Manure cooling system, fully slatted	0.170
	D 1.1.12.1	Sloping pit wall, regardless of group size	0.170
	D 1.1.12.2	Sloping pit wall, group size up to 30 piglets	0.210
	D 1.1.12.3	Sloping pit wall, group size> 30 piglets	0.180
	D 1.1.13	Fully slatted, water and manure channels	0.200
	D 1.1.14	Acid air scrubber - 95% NH_3 reduction	0.030
	D 1.1.15.1	Combi scrubber (acid) - 85% NH_3 reduction	0.100
	D 1.1.15.2	Combi scrubber (biological) - 70% NH_3 reduction	0.210
	D 1.1.15.3	Combi scrubber (acid) - 85% NH_3 reduction	0.100
	D 1.1.15.4	Combi scrubber (biological) - 85% NH_3 reduction	0.100
	D 1.1.15.5	Combi-washer (biological) - 85% NH_3 reduction	0.100
	D 1.1.15.6	Combi-washer (biological) - 90% NH_3 reduction	0.070
	D 1.1.16	Biological air scrubber - 80% NH_3 reduction	0.100
	D 1.1.17	Acid air scrubber - 90% NH_3 reduction	0.070
	D 4.1	Floating balls in the manure	0.490
	D 1.1.100	Other housing systems	0.690
Fattening pigs	D 3.1	Fully slatted	4,500
	D 3.2.1	Partly slatted	4,500
	D 3.2.2	Manure collection and flushing	1,600
	D 3.2.3	Cooling system, 170%	1,700
	D 3.2.4	Manure collected in formaldehyde	1,000

Animal species	Rav code	Description	Ammonia (kg NH_3 / place)
	D 3.2.5	Manure collected in water	1,300
	D 3.2.6	Cooling system, 200%	1,500
	D 3.2.7.1	Manure pit, metal triangular slats	1,000
	D 3.2.7.2	Manure pit, other slats	1,500
	D 3.2.8	Biological air scrubber - 70% NH_3 reduction	0.900
	D 3.2.9	Acid air scrubber - 70% NH_3 reduction	0.900
	D 3.2.10	Convex floor	1,400
	D 3.2.11	Separated manure channels	1,700
	D 3.2.12	Flushing gutters, metal triangular slats	1,200
	D 3.2.13	Flushing gutters with slats	1,700
	D 3.2.14	Acid air scrubber - 95% NH_3 reduction	0.150
	D 3.2.15.1	Combi scrubber (acid) - 85% NH_3 reduction	0.450
	D 3.2.15.2	Combi- scrubber (biological) - 70% NH_3 reduction	0.900
	D 3.2.15.3	Combi scrubber (acid) - 85% NH_3 reduction	0.450
	D 3.2.15.4	Combi scrubber (biological) - 85% NH_3 reduction	0.450
	D 3.2.15.5	Combi- scrubber (biological) - 85% NH_3 reduction	0.450
	D 3.2.15.6	Combi- scrubber (or biological ganic) - 90% NH_3 reduction	0.300
	D 3.2.16	V-shaped manure belt	1,100
	D 3.2.17	Biological air scrubber - 80% NH_3 reduction	0.450
	D 3.2.18	Acid air scrubber - 90% NH_3 reduction	0.300
	D 4.1	Floating balls in the manure	2,130
	D 3,100	Other housing systems	3,000
White veal calves	A 4.1	Acid air scrubber - 90% NH_3 reduction	0.35
	A 4.2	Biological air scrubber - 70% NH_3 reduction	1.1
	A 4.3	Acid air scrubber - 70% NH_3 reduction	1.1
	A 4.4	Acid air scrubber - 95% NH_3 reduction	0.18
	A 4.5.1	Combi scrubber - 85% NH_3 reduction	0.53
	A 4.5.2	Combi scrubber - 70% NH_3 reduction	1.1
	A 4.5.3	Combi scrubber (water scrubber, acid) - 85% NH_3 reduction	0.53
	A 4.5.4	Combi scrubber (water curtain, biological) - 85% NH_3 reduction	0.53
	A 4.5.5	Combi scrubber (water scrubber, biological) - 85% NH_3 reduction	0.53
	A 4.5.6	Combi scrubber (biological and acid) - 90% NH_3 reduction	0.35
	A 4.6	Biological air scrubber - 85% NH_3 reduction	0.53
	A 4.7	Sloping slatted floor in combination with sloping false floor under the slatted floor	2.5
	A 4.8	Slatted floor with convex rubber top layer, sealing flaps	1.9
	A 4,100	Other housing systems	3.5

Table 2.2.9 *Gross manure-N excretion of 'non-ruminants' and emission factor of other gaseous losses (other than NH_3-N) in slurry or solid manure systems, with: Emission of N-other (kg N) = Gross N -excretion * EF N-other.*

Animal group	Gross N excretion (kg N per animal place)	EF N-Other slurry (% of N)	EF N-Other solid manure (% of N)
Farrowing sows	27.25	2.4	3.5
Dry and pregnant sows	17.25	2.4	3.5
Weaned piglets	3.9	2.4	3.5
Fattening pigs	12.3	2.4	3.5
Laying hens	0.77	1.2	0.7
Broilers	0.5	1.2	0.7
White meat calves	14.3	2.4	3.5

2.2.2.5 Ammonia loss from external storage

Part of the manure goes to the external manure storage. In ANCA it is assumed that 23% of the slurry produced in the stable, and 100% of the solid manure produced in the stable (values based on Van Bruggen *et al.* (2017)) go to an external manure storage. In the external manure storage also some NH_3 losses occur, estimated at 1% of the stored manure for slurry and 2% for solid manure.

2.2.2.6 Change in TAN content due to anaerobic digestion

Part of the slurry can be fermented. This can be specified in ANCA. When manure is fermented, part of the organic N is converted to TAN. This concerns 25% of the organic N entering the digester. This percentage is based on fertilization research in which the N effect of digestate has been compared to unfermented manure (Schroder et al., 2007). The extra TAN resulting from this is calculated as follows:

First, the Norg in the slurry is calculated via:

Norg slurry (kg) = [N excretion under the tail (kg) - TAN excretion (kg)] x proportion of slurry x 0.9 + $N_{sawdust}$

The factor 0.9 concerns the correction for the mineralization of Norg during storage (10%, see section 2.2.2.2.1). If sawdust is used in the slurry section of the house, the N contained therein is added to the Norg in slurry. This happens after correction for the N mineralization of the Norg in the manure.

Then the amount of extra TAN from anaerobic digestion is calculated:

*TAN fermentation (kg) = Norg slurry (kg) x fraction of slurry fermented * 0.25*

From this point the fermented manure is considered as digestate in ANCA.

2.2.2.7 Ammonia loss during grazing

During grazing less N is lost via NH_3 emissions than in the barn. The EF of the TAN excretion during grazing was calculated in NEMA for Dutch circumstances in 2014 as a constant value of 4.0% (van Bruggen *et al.*, 2017). The ammonia loss from TAN excretion during grazing is calculated as:

NH_3-N_grazing (kg) = TAN_grazing (kg) x EF_grazing (%),

where EF_ grazing = 4.0%

2.2.2.8 Ammonia loss during manure application

The ammonia loss during manure application is calculated based on the applied TAN in combination with the EF for the different application techniques.
The amount of TAN (kg N) applied in the form of dairy manure is calculated within BEA by correcting the TAN in the manure storage ('TAN stable manure'; i.e. manure excreted and stored indoors, usually slurry) for manure import and export, if any. The manure import and export is expressed in BEA in kg N. It is assumed that both the imported and exported manure contain the same amount of TAN per kg N as the manure in the farm's storage.

The amount of TAN (kg N) applied as fertilizer is calculated as a percentage of the kg N applied:

TAN applied (kg) =% TAN manure x kg N applied,

where: % TAN manure = TAN 'stable manure' / Net N excretion

Kg N applied = Net N excretion + N manure imported - N manure exported

TAN 'stable manure' = TAN production - total gaseous Nemission $_{\text{housing + external storage}}$

The TAN (kg N) used in the form of manure from 'non-ruminants' ('intensive livestock') is calculated within BEA as:

TAN applied (kg) =% TAN manure x kg N applied, with:

Kg N applied = Total net excretion + N manure imported - N manure exported + N initial stock - N final stock, and

% TAN manure according to standard values for non-ruminants in Table 2.2.10

Table 2.2.10 *Standard TAN percentage (%) in manure of non-ruminants.*

Animal species	TAN manure (%)
Farrowing sows	67
Dry and pregnant sows	67
Weaned piglets	67
Fattening pigs	64
Laying hens	76
Broilers	62
White meat calves	72

Next, the total TAN-applied from dairy cattle manure (cattle with associated young stock), other ruminants, and non-ruminants is divided over arable land and pasture. This is done according to the farm's indication of kg N applied on grassland and arable land in BEA. Finally, the method of application (see Table 2.2.11) is also specified, and related to an EF for application. In the BEA module of ANCA the percentage of manure per application method should be specified, including the application methods for both grassland and arable land.

Table 2.2.11 *Average emission factors (kg NH_3-N per 100 kg TAN administered) per type of fertilizer and method of application for grassland and arable land (based on Velthof et al., 2012; Van Bruggen et al., 2017).*

Land use	Method of administration	Fertilizer type				
		Solid manure & solid fraction	Slurry, liquid fraction, digestate	Slurry with half part of water [1]	Mineral concentrate & blowdown-lye	Compost
Grassland	Surface application	71	71		71	69
	Trailing shoe	-	(31)	19 [3]	10	
	Slid coulter [2]	-	25		9	
	Shallow injection	-	19		8	
Arable land	Surface application	-	69		69	69
	Surface application with direct incorporation	-	22		22	
	Trailing shoe	-	36		12	
	Deep injection (>10 cm)	-	2		3	
	Shallow injection (<10 cm)		24		8	

1) Half part of water means: two parts of manure with one part of water (more water is allowed but does not lead to emissions lower than that of slurry injection) .

2) For the emission factor of a slid coulter, the average of the emission factor of a trailing foot and slurry injection is used .

3) The emission factor for the application of diluted manure with a trailing foot on grassland is maintained at a similar level as for slurry injection. The minimum dilution is 2 parts manure and 1 part water.

The ammonia emissions are calculated from the combination of the kg TAN and EF used in Table 2.2.11:

$$NH_3\text{-N fertilizer application (kg)} = \text{TAN application}_{1 \ldots n} \times EF\_\ \text{application}_{1 \ldots n}$$

Where 1 ... n = application methods in Table 2.2.11

2.2.2.9 Ammonia loss during synthetic fertilizer application

Ammonia can also volatilize from synthetic fertilizers. That is why BEA requires information about the amount of synthetic N fertilizer used. When estimating emissions, no distinction is made between soil types or land use. However, a differentiation is made according to the type of synthetic N fertilizer (Table 2.2.12).

Table 2.2.12 *Emission factors for synthetic fertilizer (EF_NH_3-N $_{fertilizer}$, kg N per 100 kg N total applied (Van Bruggen et al., 2017; Vonk et al., 2018).*

Fertilizer type	Land use	Emission factor
N fertilizers, 100% ammonium	Grassland and arable land	11.3
N fertilizers, 100% nitrate	Grassland and arable land	0.0
N fertilizers, combination of ammonium and nitrate	Grassland and arable land	2.5
Urea, granulated, without urease inhibitor	Grassland and arable land	14.3
Urea, granulated, with urease inhibitor	Grassland and arable land	5.9
Liquid urea without urease inhibitor or acid	Grassland and arable land	7.5
Liquid urea with urease inhibitor or acid	Grassland and arable land	3.1
Liquid urea applied by injection	Grassland and arable land	1.5

The ammonia emission is calculated from the combination of the applied kg of fertilizer-N and the EF from Table 2.2.12:

$$NH_3\text{-}N \text{ fertilizer applied (kg)} = \text{kg fertilizer-N applied}_{1 \dots n} \times EF\_\text{application}_{1 \dots n},$$

where 1 ... n = fertilizer type from Table 2.2.12

2.2.2.10 Ammonia loss from crops

In Figure 1.3, crops produced on own land are indicated as the 'harvestable and mowable amount of feed grown' (i.e., arable-managed roughages such as corn (whole plant corn silage 'WPCS', whole-ear corn silage 'WECS', or CCM), grass silage, fresh grass for indoor feeding; excluding roots, stubble and catch crops but including harvest losses), and the 'grown amount of pasture grass' (including the part that may be grazed by geese and grazing losses). On mixed crop-livestock farms with arable crop production, non-roughage crops are added to this. In the paragraph on BEN (paragraph 2.3.2.1) these items are calculated with $Af1_{corn}$, $AF3_{corn}$, $Af1_{cut\ grass}$, $af3_{cut\ grass}$, $Af1_{pasture\ grass}$, $AF3_{pasture\ grass}$, $Af1_{other\ roughage}$, $AF3_{other\ roughage}$, $Af1_{market\ arable}$, and $AF3_{market\ arable}$ (kg N per ha). Af1 items concern the net export (from field or mouth) in case of roughage (maize, 'cut grass', 'pasture grass', 'other roughage', and 'geese grazing'), and the export of primary products from marketable arable crops ('market arable'). Af3 items concern the harvesting, mowing and grazing losses of roughage (maize, cut grass , pasture grass, and other roughage) and the (possibly exported) by-products of marketable arable crops ('market arable'), such as straw. Ammonia losses (kg N) from all these crops are estimated at 3% (Vertregt & Rutgers, 1987) of:

$$\begin{aligned}&(GO \times (Af1_{cut\ grass} + AF3_{cut\ grass} + Af1_{pasture\ grass} + AF3_{pasture\ grass}) +\\ &SO \times (Af1_{maize} + Af3_{maize}) +\\ &ORO \times (Af1_{other\ roughage} + Af3_{other\ roughage}) +\\ &AMO \times (Af1_{market\ arable} + Af3_{market\ arable}),\end{aligned}$$

with GO, SO, ORO and AMO being, respectively, the areas (ha) of grassland, maize land, other roughage and marketable arable crops.

The area-weighted average N exports are used for $Af1_{market\ arable}$ and $Af3_{market\ arable}$. In case the by-product of the latter crops ($Af3_{market\ arable}$) remains on the land, a default value is used for the N-yield of the by-product. Regardless of whether by-products are exported, it is assumed that primary and by-products lose ammonia before harvest.

2.2.3 Comments on BEA

- No definition of the summer and winter periods has been given. BEA therefore uses an annual feed ration.
- Different EFs are used for stable emission during the housing and grazing period. Only when the barn is empty for several hours a day (such as in combination with grazing), there will be differences in emissions from the fouled floor surface. As a result (see Table 2.2.3), with 20 hours of unlimited grazing, the EF is high (40.9%) as compared to 9 hours of limited grazing (17.5%) and summer feeding (14.3%).
- It is assumed that the emission of the RAV type of barn A1.100 is equal to the emission calculated by the NEMA method of the 'not low-emission housing' within BEA. This assumption is correct when it comes to comparing or deriving the EF for the other RAV barn types. However, this assumption is debatable for a quantitative comparison (based on kg of ammonia) of the emission calculated by BEA and RAV. Indeed, there are indications that the RAV emission factor for cattle is too low (Van Bruggen *et al.* , 2017). Velthof *et al.* (2009) indicated that calculations by Smits *et al.* (2007) indicate that the RAV emission factor for dairy cattle may be up to approx. 20% higher.
- In case of manure separation on the farm, the EF of slurry will be used for the liquid fraction and that of solid manure for the solid fraction. Of the imported amount of 'synthetic fertilizer substitutes'

(liquid fraction of separated manure, digestate, mineral concentrate, blowdown lye), it is assumed that these types of fertilizer are applied on land as soon as possible after purchasing. This means that no emissions from stable and storage are included for these fertilizers.

- Different emission factors are used for the application of mineral concentrate and blowdown lye (Table 2.2.11) and slurry application. When applying mixtures of mineral concentrate (or blowdown lye) and slurry, ANCA uses the emission factors of the individual fertilizers.
- The amount of N applied is reported by the dairy farm in BEA by indicating how much N goes to the arable land. The other N is assumed to be applied to grassland. Here are potential errors:
  1. In practice, the N applied on arable land is usually calculated as cubic meters of manure times a *standard value* for N content,
  2. The calculated N in manure and storage is based on the N excretion of the herd for the current calendar year. However, there may have been stock mutations (not shown) and there may be more N in storage than calculated, for example due to N loss from feed.
- In NEMA emission percentages are provided for the stable and for the storage. In NEMA these two percentages are summed to a total emission from 'stable and storage' . BEA does that too. The BEA calculation is somewhat improved by assuming that on average 23% of the manure goes to a closed storage. The calculation can be made more farm-specific by determining more precisely which part of the manure actually ends up (shortly after excretion) in a closed storage, from which hardly any NH_3 is released and for which, given other temperatures, the assumed 10% extra mineralization of organic N no longer applies.
- If young stock are housed in the same housing type as the dairy cows, BEA makes no distinction between dairy cattle and young stock with regard to emissions. The potential error is limited because the number of young stock and TAN excretion per unit of young stock are small compared to dairy cattle.
- The emission factors used, although specified for housing systems and application techniques, are based on averages. Research has shown a large range around this average value, influenced by barn climate, ventilation, drinking and flushing water use (related to the dry matter content in manure), deliberate dilution of manure with water, acidification, additives, soil type, weather conditions (precipitation , temperature, wind), crop type and height, fertilizer application, volume of manure, distribution of manure over a year. In addition, the treatment and processing of manure (fermentation, separation) can also play a role in actual ammonia losses.
- BEA calculates the ammonia losses from the stable and storage as a fraction of the manure excreted, regardless of whether this manure is exported and, if so, at what time after excretion. Accordingly, no ammonia losses from stable and storage are attributed to manure that is imported, even if that manure remains on the farm for some time before being applied on land. Ammonia losses from application of this manure are settled of course. It is assumed that the imported manure has the same TAN percentage as the manure that is produced on the farm itself. This is not actually the case.
- In case of anaerobic digestion, BEA calculates an increase in the TAN due to the breakdown of organic N in the digester. This happens at the end of the storage period. This means that the emissions of this extra TAN are limited to losses occurring during application of digestate on land. In practice, fermentation will take place in winter and the digestate will be stored until it is applied in the growing season. Because part of the manure is stored as digestate, the TAN losses during storage will be somewhat higher due to the higher TAN content of the digestate. This is not taken into account in the calculation.
- Unlike in dairy cattle, the contribution of 'non-ruminants' to ammonia emissions is not differentiated based on feed ration composition.
- The calculation of the key figure 'ammonia-N emission per ton of milk' is based on all ammonia, including the part that is caused by non-ruminants or arable production. In case of livestock production other than dairy cattle or arable production, therefore, this key figure cannot yet be compared with that of a specialized dairy farm.

2.3 BEN: farm-specific N flows

2.3.1 Introduction

The use of nitrogen (N) is necessary to maintain soil fertility and crop yields. However, the use of N in agriculture also leads to unwanted losses to the environment. Environment impact is determined, among other things, by the N concentration in ground and surface water (mainly nitrate-N under sandy soils, and nitrate, ammonium and dissolved organic N from clay and peat soils) and the emission of the greenhouse gas N_2O (nitrous oxide). The primary purpose of this part of the ANCA calculations is to estimate the N concentration in the upper groundwater below the farm (sandy soils) or surface water within the farm (peat and clay soils) and the emission of the greenhouse gas N_2O from the soil and manure storage.

2.3.2 Calculation methods

2.3.2.1 N concentration in water

To estimate N concentrations in water, the so-called N soil surplus must be calculated. This N soil surplus is converted into an N concentration, using associations found at sites of the Dutch National Monitoring Network on Effects of Manure Policy (LMM) of RIVM and WEcR-Wageningen UR (http://www.rivm.nl / Topics / L / National_Meetnet_effects_Fertilizers).

The factor linking the N soil surplus (kg N / ha) to the N concentration (mg N / l) consists of a so-called leaching fraction (LF (kg N / kg N); i.e. the part of the N soil surplus that actually leaches and is not converted into gaseous compounds such as N_2 , N_2O and NO_x) and the precipitation surplus (PS (mm = 10000 x liter / ha), i.e. the amount of water in which the leached N is dissolved), as follows:

N concentration (mg N / l) = N soil surplus (kg N / ha) x LF (kg N / kg N) / (100 x PS (mm))

The LMM shows that LF and PS depend on the land use (grassland, arable land) and on the type of soil (Table 2.3.1). The relevant table also indicates that there are significant differences in the values of the leaching fraction and the precipitation surplus between years.

For BEN, the N soil surpluses of all grassland, maize land, the land on which other roughage is cultivated and the land on which marketable arable crops are cultivated are initially calculated separately. Based on the percentage distribution of the grassland and arable land (maize land, other roughage, marketable arable crops) over the various soil types, the weighted average soil type-specific LF and the PS of grassland and arable land are calculated separately, and subsequently the corresponding N concentration. Finally, the weighted average N concentration of the farm as a whole is calculated.

Table 2.3.1 *Leaching fraction LF and precipitation surplus PS (Fraters et al., 2012).*

Ground type	Leaching fraction (95% CI)		Precipitation surplus (10% and 90% percentile)	
	Grassland	Arable land	Grassland	Arable land **
Peat	0.05 (0.04-0.06)	0.12 (0.09-0.14) *	320 (264-379)	381 (314-432) *
Clay	0.11 (0.09-0.13)	0.34 (0.25-0.43)	311 (247-375)	353 (294-420)
Moist sand (Gt IV)	0.19 (0.16-0.22)	0.39 (0.35-0.42)	274 (221-319)	358 (304-405)
Moderately dry sand (Gt VI)	0.29 (0.25-0.33)	0.59 (0.53-0.64)	280 (226-346)	332 (297-387)
Dry sand (Gt VII)	0.37 (0.32-0.42)	0.75 (0.68-0.81)	298 (245-362)	332 (295-392)

* Not specified in Fraters *et al.* (2012) but estimated from the ratio of arable land and grass values for the other soil types.

** According to Schröder *et al.* (2007), the precipitation surplus of silage maize land, depending on the soil type, is max. 5% greater or smaller than that of the other arable land; this distinction is no longer made in ANCA.

Table 2.3.2 *Input and output items for determining the N soil surplus (kg N / ha), with an indication ('X') whether the data relate to the farm as a whole, to crops (grassland, arable land), or to crops with a distinction between the part with crops in rotation and continuous cropping.*

Input/ output	Code	Item	Scale		
			Farm	Crop	Crop & rotation
Input	In0	Nmin spring, in year x	X		
	In1	Pasture manure		X	
	In2	'stable manure' , incl. feed leftovers roughage			X
	In3	Synthetic fertilizer			X
	In4	clover		X	
	In5	deposition	X		
	In6	grazing, cutting and harvesting losses		X	
	In7	Crop residues		X	
	In8	Catch crops and green manures		X	
	In9	peat mineralization		X	
	In10	from ploughing grassland			X
	In11	Geese excretion	X	X	
	In	SUBTOTAL			
Output	Out0	Nmin spring, year x + 1	X		
	Out1	harvested from own land, including geese grazing	X	X	(X)**
	Out2	ammonia losses during grazing, (synthetic) fertilizer application, and from standing crop *		X	
	Out3	grazing, cutting and harvesting losses		X	
	Out4	crop residues		X	
	Out5	Catch crops and green manures		X	
	Out6	Formation artificial pasture			X
	Out	SUBTOTAL			
Soil surplus	In-Out	TOTAL			X

* N loss with maturing or during pre-drying.

** For the most accurate estimate of N surpluses in crop rotation and continuous copping the quantity of N output should also be specified for these two situations.

Input items

The N soil surplus is calculated based on the items indicated in Table 2.3.2. This is in line with methods used in the LMM, and in the approved Dutch Action Programs related to the European Nitrate Directive (Schröder *et al.* , 2007). At the moment, users of ANCA are not yet asked to differtiate in input between the part of the grassland and the arable land in crop rotation and the part with continuous cropping. Table 2.3.2., however, does specify this. The idea is that, if desired in future, the N concentrations estimated by BEN can be validated against observations of the participating farms, and these observations could be influenced by rotation. This concerns the input items In2, In3 and In10 and the output item Out6. Such a distinction, focusing on validation, makes sense only if, besides a distinction in the input items, a distinction is made in the exported amount of N (Out1). After all, the yields (and N and

P removal) of crops in rotation can differ from those in continuous cropping. Accordingly, soil surpluses can differ between rotation and continuous cropping not only due to differences in input, but also due to differences in output.
The items In0 (mineral soil N at the start of the year) and Out0 (mineral soil N twelve months later) are assigned a default value of 30 kg N per ha. These items have been included in accordance with preferences of the European Commission, but they are only relevant for accounting records and cancel out each other. Users of ANCA are therefore not asked for a farm-specific value.

The item In1 (pasture manure) is expressed as kg total N per ha of total grassland, initially without correction for the NH_3-N losses occuring during grazing. The items In2 ('stable manure' , i.e. manure excreted and stored indoors, usually slurry) and In3 (synthetic fertilizer) are expressed as kg N per ha of grassland and per ha of arable land. In1 is calculated based on the calculated gross N-excretion and the specified number of hours of grazing. In3 is specified by ANCA users. In2 is derived from the data on gross N excretion in the context of BEX (section 2.1), as far as this takes place indoors, after accounting for all gaseous losses from the stable and storage according to BEA (section 2.2), plus the net manure production of 'non-ruminants' (if any), after accounting for imported and exported manure, plus feed residues, but not yet corrected for the NH_3-N losses that occur when 'stable manure' is applied on land. In addition, a correction is made for stock changes: if at the end of the year there is less manure in stock than at the start, the difference (kg N / ha) is added to In2; if more manure is in stock at the end of the year than at the start, the difference is deducted from the total of manure-N in 'stable manure' applied on land:

Manure applied-N = excreted manure + feed leftovers-N - (NH_3-N $_{stable + storage}$ + exported manure) ± stock change.

The feed leftovers-N (kg N / ha) is estimated at 2 to 5%, depending on the type of feed (Table 1.1), of the total amount of feed N (kg N / ha) offered to the livestock, as follows:

Feed leftovers-N = 0.05 x (N intake in the form of conserved grass and maize silage / (1- 0.05)) + 0.03 x (N intake in the form of other self-grown roughage and wet by-products / (1-0.03)) + 0.02 x (N intake in the form of concentrates, compound feed and dairy products / (1- 0.02)),

with N uptake from the various feed materials based on data from the BEX part (section 2.1).

ANCA users then specify what amout of 'stable manure' is applied (kg N / ha) on grassland ($In2_{grassland}$), on maize land ($In2_{maize}$), on land with other roughage ($In2_{other\ roughage}$), and on the arable land with marketable arable crops ($In2_{market\ arable}$) , as follows:

Manure applied-N (kg) = ((GO x $In2_{grassland}$) + (SO x $In2_{maize}$) + (ORO x $In2_{other\ roughage}$) + (AMO x $In2_{market\ arable}$))

where,
GO = total area of grassland (ha), SO = total area of maize land, ORO = total area of other roughage and AMO = total area of marketable arable crops. Instead of specific entries for all of the aforementioned four destinations ('area x amount per ha'), the amount of manure-N in the fourth destination can also be calculated from the amount applied in the other three destinations. By dividing that fourth amount by the corresponding area, the amount per ha at that fourth destination can also be calculated.

For the calculation of the N-soil surplus, the current version of ANCA does not distinguish between the part of the grassland and the arable land in continuous cropping and the part in rotation. If this is integrated in a future version, additional data entry will be required:

- The difference in amount of 'stable manure' (kg N / ha grassland) applied on grassland in rotation and permanent grassland (ESG, positive if amount applied on crops in rotation> amount applied on continuous cropping system),
- The difference in amount of 'stable manure' (kg N / ha arable land) applied on arable land in rotation and continuous cropping (ESB, positive if amount applied on crops in rotation> amount applied on continuous cropping system),
- The difference in amount of synthetic fertilizer (kg N / ha of grassland) applied on grassland in rotation and permanent grassland (EKG, positive if amount applied on crops in rotation> amount applied on continuous cropping system),
- The difference in amount of synthetic fertilizer (kg N / ha arable land) applied on arable land in rotation and continuous cropping (EKB, positive if amount applied on crops in rotation> amount applied on continuous cropping system),
- Total farm area (TO, ha), the total area of grassland (GO, ha), the area of grassland in rotation (WHO, ha) and the area of arable land in rotation (WBO, ha), the total area of arable land (BO, ha) and the 'stable manure' and synthetic fertilizer application are calculated for permanent grassland, permanent arable cropping, grassland in rotation and arable land in rotation, as follows:

In2 on grass in rotation = ((GO x $In2_{grassland}$) + ((GO-WHO) x ESG)) / GO
In2 on permanent grassland = In2 on grass in rotation - ESG

In2 on arable land in rotation = ((BO x $In2_{arable\ land}$) - ((BO - WBO) x ESB)) / BO
In2 on permanent arable cropping = In2 on arable land in rotation + ESB,

where BO = TO - GO and
$In2_{arable\ land}$ = ((SO x $In2_{maize}$) + (ORO x $In2_{other\ roughage}$) + (AMO x $Inn2_{market\ arable}$)) / (SO + ORO + AMO),

Furthermore, the following applies:
In3 on grass in rotation = ((GO x $In3_{grassland}$) + ((GO-WHO) x EKG)) / GO
In3 on permanent grassland = In3 on grass in rotation - EKG
In3 on arable land in rotation = ((BO x $In3_{arable\ land}$) - ((BO - WBO) x EKB)) / BO
In3 on permanent arable land = In3 on arable land in rotation + EKB

where BO = TO –GO and

$In3_{arable\ land}$ = ((SO x $In3_{maize}$) + (ORO x $In3_{other\ roughage}$) + (AMO x $In3_{market\ arable}$)) / (SO + ORO + AMO)

In the above it seems to be assumed that within the arable land there are no more than three 'types' of destinations (maize, other roughage and marketable arable crops) and that ANCA therefore only requires data about the area and organic and synthetic fertilizer application of those three destinations. In reality, however, the current version of ANCA allows to enter the aforementioned data for three types of maize (WPCS, WECS, CCM), three types of other roughage crops (grain WPS, lucerne, field beans, WPS) and more than ten types of marketable arable crops (see Table 2.3.3). An area-weighted average is calculated based on this information.

As regards the contribution of clover in grassland, the item In4 (N fixing by leguminous plants, kg N per ha) is calculated as the product of the estimated amount of dry matter grown (before deduction of field losses) in the form of clover (as 'clover percentage' in harvested amount of grass plus clover) and an assumed fixation of 45 kg N per tonne of dry matter in the form of clover (Elgersma & Hassink, 1997; Schils, 2002). The amount of grown dry matter in the form of clover is defined as the product of kg DM per kg N in the crop and the sum of the net harvested crop and field losses: ton DM / kg N x ($Af1_{cut\ grass}$ + $Af1_{pasture\ grass}$ + $Af3_{cut\ grass}$ + $Af3_{pasture\ grass}$). It should also be noted that the aforementioned 'clover percentage' is not equal to the visually estimated 'clover density' in grass clovers. The relationship between the two is roughly: clover percentage / clover density = 0.82 (Schils *et al.* , 2001).

With regard to field beans and alfalfa, the contribution to N-fixation is estimated at 100 and 300 kg N per hectare per year, respectively. A fixed contribution of 60 kg N per hectare per year is assumed for leguminous green manures, assuming that leguminous plants fix 20 kg N per ton dry matter and leguminous green manures produce 3 tons dry matter per hectare (Schröder *et al.* , 1997; Schröder *et al.* , 2003).

The item In5 (N deposition) averages about 30 kg N per ha per year (Anonymus, 2009) but varies from less than 20 (parts of the north and northwest Netherlands) to more than 50 (parts of the east and south of the Netherlands) kg N per ha per year. Regional specification takes place on the basis of area-specific data on N-deposition (Anonymus, 2013).

The item In6 (cumulative residual effects of grazing, cutting and harvesting losses from previous years) is defined for grassland ($In6_{grassland}$, kg N / ha) as the sum of the grazing and cutting losses ($Af3_{cutt\ grass}$ + $Af3_{pasture\ grass}$, kg N / ha), for maize land ($In6_{maize\ land}$, kg N / ha) and other roughage land ($In6_{other\ roughage}$, kg N / ha) as the harvest losses of those crop groups. The grazing losses are set at 15-20% of the N yield of pasture cuts (see Table 1.1) and the grass and alfalfa cutting losses ('mowing, teddering, windrowing, loading') at 5% of the N yield of cuts. Harvest losses from maize land ('chopping, loading') are set at 2% of the N yield. For the time being, no crop losses are assumed for roughage crops other than grass, alfalfa and maize, and for marketable arable crops.

Elsewhere in this section it is explained how the above N-yields are derived. Formally the principle described above that In6 equals the harvest, cutting and grazing losses not right because under BEA plus (Section 2.2.2.9) it is assumed that some of these losses occur in the form of ammonia. In theory, these ammonia losses should be deducted from In6. Since it concerns a cross post and the term is not part of the numerator and denominator of calculations, the effect on ANCA results is nil.

The item In7 (crop residues) for grassland ($In7_{grassland}$) is set at 75 kg N / ha (Velthof & Oenema, 2001). It is assumed that this input item in permanent grassland has an equal output every year (see item Out4, later in this section). For maize land (WPCS, WECS and CCM) ($In7_{maize\ land}$), the value of this annual supply post, as far as roots and stubble are concerned, is set at 15 kg N / ha (Schröder *et al.* , 2016). Irrespective of the value, this input item is also offset by an equally large output item (Out4) for maize in continuous cropping. In case of residual effects from grazing, cutting and harvesting losses (In6) and crop residues (In7), it is assumed that these N input items benefit the crops from which they originate in grassland and maize land (WPCS, WECS and CCM). The fact that in a rotation system this is not true for each phase of rotation is currently ignored.

If the residual plant material from WECS or CCM is not removed from the field, crop residues consist of more than just roots and stubble. For this (default) values are assumed as shown in Table 2.3.3. The crop residues of the non-maize roughage and marketable arable crops (which, as previously indicated, are assumed to have no harvest losses and only crop residues in the form of roots and stubble and any by-products left behind) are calculated as shown in Table 2.3.3. Also for these crops, it is assumed that the output is equal to the input. In ANCA, the amount of input (In7) is not calculated in the first instance, but the output (Out4), because the output can be made crop-specific while the input is not is determined by the crop itself but by the preceding crop(s). Since the crop rotation is not exactly known, an area-weighted average value of Out4 is calculated. After this the value of In7 for all non-maize roughage crops and marketable arable crops is equated to that average value of Out4.

Table 2.3.3 *Levels in main product and by-product for the indicated dry matter content (kg per tonne fresh) of various arable-managed forage crops and marketable arable crops, as well as the estimated amounts of N in crop residues, in the form of (non-removed and therefore unweighted) by-products (kg per ha) and (based on the estimated main yield) root and stubble residues (kg N per ha). (Schröder et al., 2015).*

Crop	Main product:			By-product:			Crop residue		
							By-product	Roots and stubble *	
	DS	N	P_2O_5	DS	N	P_2O_5		Min, Max	Factor
WPS grains	550	8.9	3.8	-	-	-	-	10, 30	0.25
Lucerne	160	5.8	1.4	-	-	-	-	10, 225	0.55
Red clover	160	5.8	1.4	-	-	-	-	10, 225	0.55
Beets	260	1.8	0.9	160	3.4	0.7	34.5	10, 30	1.06
Maize	750	13.5	5.2	400	2.8	0.7	18.8	15, 15	n, v, t,
Grains, coarse grain	750	13.5	5.2	400	2.8	0.7	18.8	10, 70	0.62
Grains, small grain	840	17.8	7.9	840	5.6	1.9	4	10, 30	0.25
Grass seed	830	21	10.1	830	7.2	3.7	3	10, 40	1.27
Legumes	840	34.6	9.4	840	21	4.6	3	10, 30	0.17
Potatoes	200	3.3	1.1	-	-	-	-	10, 60	0.36
Seed potatoes	200	3	1.1	-	-	-	-	10, 100	1.6
Onions and bulbs	100	2.2	0.7	-	-	-	-	10, 20	0.17
Leafy vegetables	75	2.5	0.7	-	-	-	-	10, 50	0.81
Non-leafy vegetables	85	2.6	1.1	85	3	0.9	10	10, 30	0.22
Other	1000	5	1.0	-	-	-	-	10, 20	0.3
Unfertilized catch crop							40		
Non-leguminous green manure							50		
Leguminous green manure							60		

* N in roots and stubble = MIN (Max, (MAX (Min, (factor x N in main product)))).

The value assigned to the item In8 (catch crops and green manures) is 40 kg N / ha for (fertilized) catch crops (mainly cultivated after maize), 50 kg N / ha for non-leguminous (fertilized) green manures and 60 kg N / ha for (fertilized) leguminous green manures.

The value assigned to the item In9 (peat mineralization) is 235 kg N per ha (Kuikman *et al.* , 2005). If only part of the farm consists of peat soil, the peat mineralization is reduced proportionately.

The item In10 refers to the input of N to arable land from ploughed grassland. This means that In10 = 0 for permanent grassland, grassland in rotation and permanent arable land. In arable land in rotation, In10 is equated with the product of the duration of the previous grassland phase and an annual sod build-up of 75 kg N per ha (Velthof & Oenema, 2001) with a maximum of 300 kg N per ha, divided by the duration of the arable land phase:

In10 with arable land in rotation = (MIN (300, (75 x duration grassland phase)) / (duration arable land phase)

The item In11 refers to the supply of nitrogen and phosphate by the excretion of grazing geese is estimated as the total excretion from geese ($N_{eg}T$, $P_{eg}T$) multiplied by the part that will have been excreted on the grazed plots. This part is estimated based on the behavior of the geese. The geese fly with an empty stomach from resting areas (on water) to the plots to be grazed and immediately start to graze. Two hours after flying in, excretion starts. Grazing continues until the animals fly back to a resting area. In that resting area, the last feed ingested is still excreted after digestion. A rule of thumb for grazing time per day and excretion is 10 hours. Since excretion starts 2 hours after grazing, excretion on the grazed plots is assumed to be 8 hours per day, and equal to 80% of the total excretion. Total excretion is derived from the balance between intake and excretion as established in husbandry systems. Values were used from the animal group that is most representative of geese in the wild: parent animals of ducks. Nitrogen excretion for this animal group is 84% of the intake, and 80% for phosphate (De Buisonjé *et al.*, 2009)).

The grass intake (as dry matter) by geese, above a certain damage threshold, is determined by appraisal. Conversion from dry matter intake to N and P intake (NOP_{goose}) takes place via the N and P content in pasture grass (see BEX section). The goose manure excretions $N_{eg}T$ and $P_{eg}T$ are then calculated as:

$N_{eg}T$ = N intake * 84% * 0.8
$P_{eg}T$ = P intake * 80% * 0.8

Output items
Elsewhere in this section it is explained how the item Out1 (harvested from own land, including geese feeding) is calculated.

The item Out2 (ammonia losses during grazing, from manure and fertilizer, from crops in the field) is derived from the BEA section (section 2.2). The term Out3 (grazing, cutting and harvesting losses) is a cross post equal to item In6, in the sense that the value of In6 is based on the calculated value of Out3. The reasoning behind this is that the input can only be maintained by a comparable (annual) investment in the soil stock, comparable to the cross posts In0 and Out0. From the same line of thought, the item Out4 (crop residues) is equal to In7. The item Out5 (catch crops), as elaborated above, is set at 40-60 kg N per ha and is only applicable to arable land.

The item Out6 (formation artificial pasture) refers to the formation of a new sod under grassland in rotation (a so-called artificial pasture), which is sown after a period of arable land. This item contributes 75 kg N per ha per year for the entire duration of the grassland phase with a maximum of 300 kg N per ha. This means that if the grassland phase lasts longer than 4 years, it is assumed that the same amount of N will be released annually from roots and stubble and added annually to roots and stubble.

Harvested from own land
The item Out1 (harvested from own land via 'mouth' or 'leaving the field' (i.e. after deduction of grazing, mowing and harvesting losses but before deduction of conservation and feeding losses), or harvested to leave the farm as arable crops for sale, kg N / ha), is calculated as follows. For the crops that are used on the farm itself ('roughage'), Out1 is calculated based on the quantity of roughage included in the BEP part (after conversion based on N / P ratios) in the form of pasture grass (NOP_{pature}, kg N), silage or fresh grass fed indoors ($NOP_{cut\ grass}$, kg N), corn silage ($NOP_{corn\ silage}$, kg N) and grazed by geese (NOP_{goose}, kg N, for calculation, see previous text in this section). The following applies for output in the form of pasture grass ($Out1_{pasture}$) and grazing losses ($Out3_{pasture}$):

$$Out1_{pasture} = (NOP_{pasture} + NOP_{goose}) / GO,$$

with GO (ha) = total grassland area.

The amount of grass grown (above ground, excluding stubble) in the form of pasture grass (kg N / ha) ($Out1_{pasture}$ + $Out3_{pasture}$) is equal to:

$$Out1_{pasture} + Out3_{pasture} = Out1_{pasture} \times (100 / (100\text{-grazing loss}))$$

with grazing loss in percentage, according to Table 1.1.

When feeding fresh grass and silage grass, the calculation of what has grown based on what is supposed to be ingested by animals is more complicated, because feeding losses and, possibly, conservation losses will occur besides field losses. In addition, the purchase and stocking of roughage must be settled.

For the amount of cut grass (stable feeding and silage) (kg N) from own land ($NOP_{cut\ grass\_ownland}$) taken up:

$$NOP_{cut\ grass\_ownland} = (NOP_{cut\ grass} - NOP_{cut\ grass\_purchased})$$

where $NOP_{cut\ grass}$ is the total amount of freshly fed and ensiled grass ingested from both purchased grass and home-grown grass, and $NOP_{cut\ grass\_purchased}$ from the grass (stable feeding and silage) ingested in the relevant year (after correction for stock changes and feeding losses of that purchased grass):

$$NOP_{cut\ grass\_purchased} = (((\text{purchased fresh grass N and silage grass N} \times (100\text{-conservation loss}) / 100) - \Delta \text{ N grass silage}) \times (100\text{-feeding loss}) / 100)$$

The conservation loss (expressed as a percentage according to Table 1.1) takes into account that also purchased grass silage is exposed to loss. The term Δ Ngraskuil indicates changes in stock of grass silage (positive values indicate an increase) in the past 12 months. The feeding loss (in percentages according to Table 1.1) settles that feeding losses also occur with purchased fresh grass or silage grass.

The amount of fresh grass and silage grass (kg N) from own land ($NAAN_{cutt\ grass\_ownland}$) is then calculated from $NOP_{cut\ grass\_ownland}$:

$$NAAN_{cut\ grass\_ownland} = NOP_{cut\ grass\_ownland} / (100 - \text{feeding loss}) / 100$$

Then for the harvested amount of cut grass N (kg N) from own land ($NDAM_{cut\ grass}$):

$NDAM_{cut\ grass} = NAAN_{cut\ grass\_ownland} / ((100\text{-conservation loss}) / 100)$, whereby it must be taken into account that not all grass that is cut is conserved (i.e. in the case of summer stall feeding).

$Out1_{cut\ grass}$ can be derived from this, as follows:

$$Out1_{cut\ grass} = NDAM_{cut\ grass} / GO$$

Finally, the amount of grass grown (above ground, excluding stubble) in the form of fresh grass (for summer stall feeding) or silage grass (kg N / ha) from own land ($Out1_{cut\ grass}$ + $Out3_{cut\ grass}$) is equal to:

$$Out1_{cut\ grass} + Out3_{cut\ grass} = Out1_{cut\ grass} \times (100 / (100 - \text{cutting loss}))$$

The above calculation of Out1 for grassland is performed separately for production grassland and natural grassland.

Similarly, for the maize silage:

For the amount of maize (kg N) taken from the home country ($NOP_{maize\_ownland}$):

$NOP_{maize\_ownland} = (NOP_{maize} - NOP_{maize\_purchased})$

where NOP_{maize} is the total amount of ingested maize from both purchased and home-grown maize (WPCS, WECS and CCM), and $NOP_{maize\ purchased}$ is maize purchased in the concerning year (after adjustment for stock changes and feeding losses of the purchased maize):

$NOP_{maize\_purchased}$ = (((purchased maize N x (100 conservation loss) / 100) - ΔNmaize silage) x (100 feeding loss) / 100)

The conservation loss (in percentages according to Table 1.1) settles that purchased maize silage is also exposed to conservation losses. The term Δ Nmaize silage refers to changes in the stock of maize silage (positive values indicate increase) in the past 12 months. The feeding loss (in percentages according to Table 1.1) settles that feeding losses also occur with purchased maize.

The amount of maize (kg N) from own land ($NAAN_{maize\_ownland}$) is then calculated from $NOP_{maize\_ownland}$:

$NAAN_{maize\_ownland} = NOP_{maize\_ownland}$ / (100 – feeding loss) / 100

Subsequently, for the harvested amount of maize N (kg N) from own land ($NDAM_{maize}$):

$NDAM_{maize} = NAAN_{maize\_ownland}$ / ((100-conservation loss) / 100).

From this $Out1_{maize}$ can be derived if:

$Out1_{maize} = NDAM_{maize} / SO$,

with SO = total area (ha) of maize land (WPCS, WECS and CCM). Finally, the (above ground, excluding stubble) grown amount of maize (kg N / ha) of own land ($Out1_{maize} + Out3_{maize}$), is equal to:

$Out1_{Maize} + Out3_{Maize} = Out1_{Maize}$ x (100 / (100-Harvesting Loss)) with harvesting loss (%) according to Table 1.1.

Similarly, for other roughage:

For the ingested amount of other roughage (kg N) from own land ($NOP_{other\ roughage\ own\ land}$), the following applies:

NOP other $_{other\ roughage\ own\ land}$ = ($NOP_{other\ roughage}$ - $NOP_{other\ roughage\_purchased}$)

where $NOP_{other\ roughage}$ is the total amount of roughage ingested from both purchased and home-grown roughage, and $NOP_{other\ roughage\_purchased}$ is purchased - the ingested roughage from purchased roughage in the year concerned (after adjustment for stock changes and feeding losses of that purchased roughage):

$NOP_{other\ roughage\_purchased}$ = (((N in purchased other roughage x (100-conservation loss) / 100) - Δ Nother roughage silage) x (100-feeding loss) / 100)

The conservation loss (in percentages according to Table 1.1) settles that also purchased other roughage is exposed to conservation losses. The term ‘Δ Nother roughage silage’ indicates changes in the stock of these types of silage (positive values indicate increase) in the past 12 months. The feeding loss (in percentages according to Table 1.1) settles that feed losses also occur with purchased roughage.

Then from $NOP_{\text{other roughage own land}}$ the offered quantity of other roughage (kg N) from own land ($NAAN_{\text{other roughage own land}}$) is calculated:

$$NAAN_{\text{other roughage own land}} = NOP_{\text{other roughage own land}} / (100 - \text{feeding loss}) / 100$$

Then, the following applies to the amount of N in harvested other roughage (kg N) from own land ($Ndam_{\text{other roughage}}$):

$$Ndam_{\text{other roughage}} = NAAN_{\text{other roughage own land}} / ((100\text{-conservation loss}) / 100).$$

From this $Out1_{\text{other roughage}}$ can be derived as follows:

$$Out1_{\text{other roughage}} = NDAM_{\text{other roughage}} / ORO,$$

Finally, the amount of other roughage (kg N / ha) grown on own land (above ground, excluding stubble) ($Out1_{\text{other roughage}}$ + $Out3_{\text{other roughage}}$) is equal to:

$Out1_{\text{other roughage}} + Out3_{\text{other roughage}} = Out1_{\text{other roughage}} \times (100 / (100 \text{ harvest loss}))$ with harvest loss (%) as stated in Table 1.1.

The current ANCA can also deal with dairy farms with arable production of which the harvest is marketed. To this end, the N exported in marketable products ($Out1_{\text{market arable}}$, kg N / ha) must be calculated. This is done by entering the number of hectares of the arable crops listed in Table 2.3.3 and the average yield of those crops in the relevant year. Finally, the N output is calculated by multiplying the yields by crop-specific standard values as listed in Table 2.3.3. For arable crops not included in the table, it is assumed that they have a standard output of 150 kg N / ha. This figure is based on the average lump sum of a rotation plan consisting of 25% winter wheat, 25% ware potatoes, 25% sugar beet and five times 5% of summer barley, summer wheat, grass seed, grain maize and seed onions, each with assumed average yields such as stated by the Dutch Statistical Office (CBS) for the period 2009-2013, whereby only the main products are considered to have been removed. Hence:

$$Out1_{\text{market arable}} \text{ (kg N / ha)} = (\textstyle\sum_1^n \mathrm{BOn} \times ((\mathrm{YHn} \times \mathrm{CNHn}) + (\mathrm{YBn} \times \mathrm{CNBn})))/\mathrm{AMO}$$

With BOn = arable land area with crop n (ha), YHn = yield of main product of crop n (tons of fresh / ha), YBn = yield of removed by-product of crop n (tons of fresh / ha), CNHn = N content of main product (kg N / ton fresh), CNBn = N content of by-product (kg N / ton fresh) and AMO = total area (ha) of area of marketable arable crops.

Figure 2.3.1 provides a summary flow chart. This flow chart is limited to the crops that are processed on the farm by the livestock (pasture grass, silage grass, maize and other roughage) or which are eaten by geese. On some farms, the complete output (Out1) also needs to be supplemented with the nutrients that are reported to be removed in the form of arable crops.

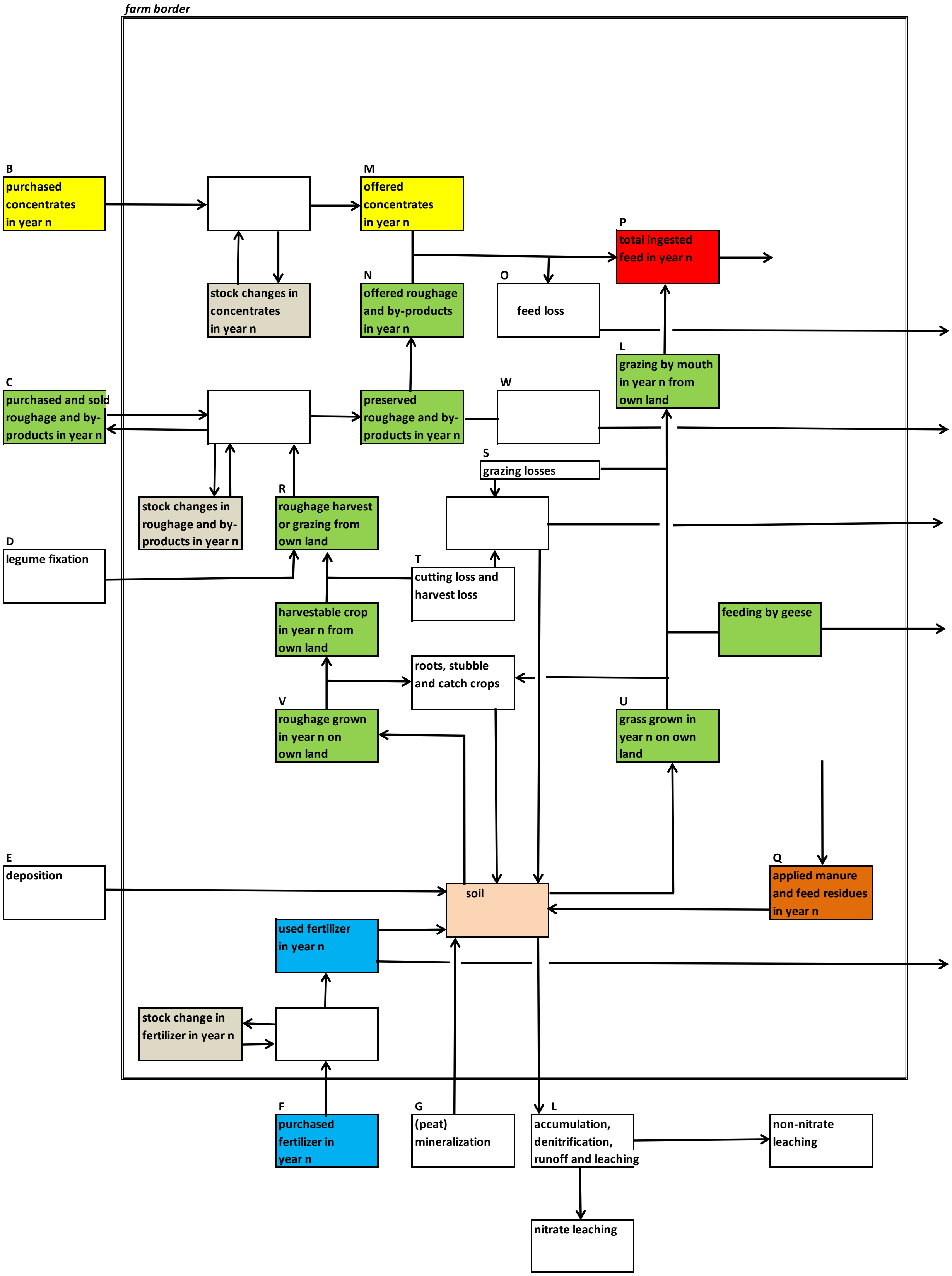

Figure 2.3.1 *Nutrient flows involved in the calculation of the soil-N surplus (and possibly nitrate concentration in receiving water) based on the estimated feed-N intake for specialized dairy farms without arable branch.*

Nitrogen Use Efficiency (NUE)

The previous paragraphs described the (un) balance of N input and N output of the soil balance. The N use efficiency in this part of the cycle (N-efficiency$_{soil}$) is equal to the fraction of the N input (after deduction of ammonia losses from grazing and application of (synthetic) fertilizer) that leads to utilizable N-output (output 'via mouth, field, and / or yard', including feeding by geese). Choices must be made with regard to whether or not to include cross posts (Nmin spring, grazing- cutting- and harvesting losses, crop residues, catch crops, fixation of N ín and the release of N from grassland in rotation) in numerator and denominator. This also applies to the way in which the items In5 (N-deposition) and Out2 (ammonia losses) must be handled: these are also cross posts at a higher scale level because ammonia deposition cannot exist without ammonia emissions.

On the other hand, N input via deposition is not influenced by an individual ANCA user and this does not only take place within the company boundaries. This also applies indirectly to In9 (peat mineralization). Although this item is not influenced by an individual ANCA user, just like deposition, it is to some extent a consequence of jointly taken agricultural decisions. Considering all this, ANCA defines the N use efficiency in the soil compartment as:

N-efficiency$_{soil}$ = (Out1 + Out3) / (In1 + 2 + 3 + 4 + 5 + 6 + 9 + 11 - Out2)

2.3.2.2 Emission of N_2O from the soil

This section describes the method of calculating the average annual N_2O emissions from the soil on a farm in the Netherlands. This emission is initially calculated in kg N_2O-N per farm. Soil emissions make the largest contribution (approximately 80%) to total N_2O emissions from a dairy farm (based on unpublished results from Dutch farms in the 'Dairyman' project). Other sources of N_2O emissions from the farms, namely those from manure storages, are discussed in section 2.3.2.3.

This section starts with a description of how indirect soil emissions can be calculated. At present ANCA does not yet include these indirect soil emissions, because these do not occur within the farm, but are a direct result of N volatilization, runoff and leaching from the farm.

The generally accepted 'Tier 1' calculation rules of the IPCC (2006) are used to calculate N_2O emissions from the soil. Where possible, the emission factors of the simple 'Tier 1' scheme of IPCC have been replaced by Dutch emission factors specified for land use and soil type by Velthof & Mosquera (2011) based on the most recent field research in the Netherlands (see Table 2.3.4) . In addition, the calculations are also tailored to the specific farming situation as indicated by ANCA user (farm-specific N-flows).

The calculated N_2O emissions relate to the emissions caused by humans ("human-derived"). Together with the so-called background emission ('background emission') they form the total N_2O soil emissions from a farm.

The IPCC's calculation method estimates the N_2O soil emission as a fraction of an N input in / to the soil. The total calculation method therefore consists of quantifying the relevant N-flows on the farm and the associated emission factors. As previously indicated, the so-called indirect N_2O emissions are the result of volatilization ('vol') and leaching ('lea') of N and they are calculated according to equations 2.3.1 and 2.3.2 (see Table 2.3.4 for explanation of terms / codes and values of emission factors):

N_2Oem (vol) = EF (vol) * Nloss (vol) (Eq 2.3.1)

with Nloss (vol) = total NH_3 -N loss according to BEA (including ammonia losses from standing crops and windrows) in kg NH_3 -N, hence Out2 x BO.

N_2Oem (lea) = EF (lea) * Nloss (lea) (Eq 2.3.2)

with Nloss (lea) = N soil surplus x LF (according to BEN).

As soil conditions outside the farm are (relatively) unknown, the equations Eq 2.3.1 and Eq 2.3.2 use emission factors that the IPCC has drawn up (Tier 1) in combination with the farm-specific (total) loss of N via volatilization and leaching. The relevant N flows are determined in BEA and BEN.

For the calculation of direct N_2O soil emissions from the farm, the following N flows are distinguished: chemical fertilizer ('cf', equation Eq 2.3.3), organic fertilizer ('or', equation Eq 2.3.4), N-excretion in urine and dung by animals on pasture ('an', equation Eq 2.3.5), net N-input in the soil from N-fixation by leguminous plants, e.g. clover ('cl', equation Eq 2.3.6), N input by crop residues ('cr', equation Eq 2.3.7), organic matter depletion in mineral soils ('om', equation Eq 2.3.8) and organic matter depletion due to dewatering peat soils ('pt', equation Eq 2.3.9). With regard to the item 'N-excretion on pasture', this consists of pasture manure excreted by the livestock (In1) plus the N added in the form of goose manure (In11). Each flow (except in equation Eq 2.3.9) must be quantified separately for the grassland and the arable part of the farmland and for the fraction of the farm that consists of mineral or peat soil because the emission factors are different (in total maximum 4 categories, see Table 2.3.4). If the distribution of both land use types (grassland and arable land) between mineral and peat soil is unknown, the dominant soil type of the farm is chosen. An N_2O emission is calculated for each N flow, each land use type and, within that, continuous cropping or crops in rotation (see also Table 2.3.4).

The N flows associated with fertilization (equations 2.3.3 and 2.3.4) and total N excretion on pasture (manure and urine; equation 2.3.5) are grafted from information previously used for the calculation of the N concentration in water in BEN.

N_2Oem (cf) = EF (cf) * Ninp (cf) (Eq 2.3.3)

with:

Ninp (cf) on grass = $In3_{grassland}$ x GO

Ninp (cf) on arable land = $In3_{arable\ land}$ x BO,

with $In3_{arable\ land}$ = area-weighted average of $In3_{maize\ land}$, $In3_{other\ roughage}$ and $In3_{market\ arable}$ and

EF (cf) according to Table 2.3.4.

N_2Oem (or) = EF (or) * Ninp (or) (Eq 2.3.4)

with:

Ninp (or) on grass = $In2_{grassland}$ x GO

Ninp (or) on arable land = $In2_{arable\ land}$ x BO,

with $In2_{arable\ land}$ = area weighted average of $In2_{maize\ land}$, $In2_{other\ roughage}$ and $In2_{market\ arable}$ and

EF (or) according to Table 2.3.4.

N_2Oem (an) = EF (an) * Ninp (an) (Eq 2.3.5)

with:

Ninp (an) = (In1 + In11) x GO, and

EF (an) according to Table 2.3.4.

The N-flow associated with N-fixation by leguminous plants (equation Eq 2.3.6) does not concern the total N-fixation, but the part that ends up in the soil via crop residues of the leguminous plants. IPCC assumes that no N_2O is produced during the fixation process, so that no direct N_2O emission takes place from the part that is harvested. In BEN, an estimate is made of the total N fixation on the farm based on the area of grassland and the proportion of white clover in it and the area of alfalfa and field beans. The N content of the crop residue of white clover is estimated as $In4_{clover}$ x 0.33. The N-content of the crop residues of alfalfa and field bean are estimated as $Out4_{alfalfa}$ and $Out4_{field\ bean}$ according to Table 2.3.3. For the N_2O emissions, a distinction must be made between mineral soil and peat soil (Table 2.3.4). The calculation is as follows:

$N_2Oem\ (cl) = EF\ (cl) * Ninp\ (cl)$ (Eq 2.3.6)

with:

$Ninp\ (cl) = (In4 \times GO \times 0.33) + (Out4_{alfalfa} \times LO) + (Out4_{field\ bean} \times VO)$ where GO, LO and VO refer to the areas (ha) of grassland, alfalfa and field bean, respectively ,

and EF (cl) according to Table 2.3.4 with weighted values based on mineral soil and peat soil shares.

In the IPCC 'Tier 1' calculation methodology, the N that ends up in the soil via crop residues on the field also forms a source of N_2O emission (equation Eq 2.3.7). IPCC uses an adapted definition of crop residues; in addition to the root and stubble residues from the arable land (Out4), crop residues also include grazing, cutting and harvesting losses from grassland and arable land (Out3), as well as crops cultivated after the main arable crop (i.e. catch crops after maize and green manures). IPCC (2006) uses a different calculation method for the N_2O emission that is linked to crop residues in the form of the root and stubble residues of grassland. IPCC (2006) states that '*The nitrogen residue from perennial forage crops is only accounted for during periodic pasture renewal, i.e. not necessarily on an annual basis as is the case with annual crops*'. This means that the average number of hectares of grassland that is renewed annually must be available. This concerns both reseeding grassland on former grassland and reseeding grassland on former arable land. For grass in rotation with arable crops, an N fixation is assumed of 75 kg N per ha per year (with a maximum of 300 kg N per ha) which is released during the arable phase. This amount includes an increase in soil N during the grassland phase. For grass that is re-sown on ploughed grassland, the amount of N in the sod (only the N in the grass, i.e. the roots and stubble, during grassland renewal) is estimated at an average of 190 kg N per ha (Van Dijk *et al.* , 1996; Conijn & Taube, 2004; Conijn 2004).

Based on the above, the N_2O emissions from crop residues are estimated as follows:

$N_2Oem\ (cr) = EF\ (cr) * Ninp\ (cr)$ (Eq 2.3.7)

with:

$Ninp\ (cr) = GO \times In6_{grassland} + SO \times Out3_{maize\ land} + ORO \times Out3_{other\ roughage}$

$+ BO \times Out4_{arable\ land} + SO \times Out5_{maize\ land} + (BO-SO) \times Out5_{non\text{-}maize\ land}$

+ (fraction of (GO-WHO) / GO that is re-sown annually on average on ploughed grassland x 190) + $WHO_{<5} \times 75$

With:

GO, BO, SO, ORO, WHO, WHO <4 = areas of, respectively, all grassland, all arable land, maize land (WPCS, CCM, WECS), other arable-managed roughage, grassland in rotation and grassland in rotation with a maximum age of 4 years, and

$In6_{\text{grassland}} = Out3_{\text{cut grass}} + Out3_{\text{pasture}}$, and

$Out4_{\text{arable land}}$ = area-weighted average of the crop-specific crop residues according to Table 2.3.3, and

$Out5_{\text{non-maize land}}$ = area -weighted average of the N-content of green manure on arable land excluding maize land in the form of fallow (Out5 = 0), non-leguminous green manure (Out5 = 50) and leguminous green manure (Out5 = 60), and

EF (cr) according to Table 2.3.4 with weighted values based on mineral soil and peat soil shares.

The last two sources of direct N_2O emission from the soil are related to a decrease in the stock of organically bound N in the soil (equation 2.3.8). The following situations may occur with mineral soils: (a) in permanent grassland (with / without grassland renewal) and in permanent arable land, there may be a gradual decrease per year and (b) during the arable land phase after tillage of grassland in rotation systems, a decrease will occur. Decreases as referred to under a) are not yet quantified in BEN. Decreases as referred to under b) have already been estimated using equation 2.3.7 due to the annual accumulation in grass and soil of 75 kg N per hectare of grassland in rotation. This N is released again with the total additional mineralization (kg N per ha per cycle) that occurs during the arable land phase due to degradation of the grass sod and soil organic matter (see section 2.3.2.1).

In the Netherlands, dewatering of peat soils for dairy farms results in a gradual decline of the soil and additional degradation of the soil organic matter. Dutch data is used for the quantification of the additional N input (see Table 2.3.4), including an annual peat mineralization of 235 kg N / ha. The N_2O emission associated with the peat mineralization is estimated as follows:

$N_2Oem\ (pt) = EF\ (pt) * Ninp\ (pt)$ (Eq 2.3.8)

with:

Ninp (pt) = TO x fraction peat soil in total land area x 235,

and EF (pt) = 0.02 (see Table 2.3.4).

To calculate the total N_2O emission at farm level, emissions of equations 2.3.1 to 2.3.8 are summed (in kg N_2O-N per year) and the soil emissions under unfertilized conditions are added. The IPCC (2006) reports on this: '*Natural N_2O emissions on managed land are assumed to be equal to emissions on unmanaged land. The latter emissions are very low. Therefore, nearly all emissions on managed land are considered anthropogenic. Estimates using the IPCC methodology are of the same magnitude as total measured emissions from managed land. The so-called 'background' emissions estimated by Bouwman (1996) (i.e., approx. 1 kg N_2O – N / ha / yr under zero fertilizer N addition) are not 'natural' emissions but are mostly due to contributions of N from crop residue. These emissions are anthropogenic and accounted for in the IPCC methodology'*.

For arable land, the IPCC has included the annual input of crop residues (equation 2.3.7), which includes emissions from the aforementioned unfertilized arable land, but this has not yet been done for grassland. As a result, emissions from unfertilized grassland have not yet been included. Two situations are distinguished:

a. The emission of unfertilized grassland on mineral soils (N_2Oem (backgr_grassl_m)) is estimated at an average of 1 kg N_2O-N per ha per year (Velthof *et al.*, 1996) and is multiplied by the number of hectares of grassland on the farm:

N_2Oem (backgr_grassl_m) = GO x (1 - fraction peat soil within TO) x 1 (Eq 2.3.9)

b. The emission of unfertilized grassland on peat soils (N_2Oem (backgr_grassl_p)) is estimated at an average of 5.3 kg N_2O-N per ha per year (Velthof *et al.* , 1996). However, account has already been taken of 235 x 0.02 = 4.7 kg N_2O-N emission per ha peat soil as a result of additional mineralization on dehydrated peat soils (see equation 2.3.8 and Table 2.3.4). Correcting for this implies:

N_2Oem (backgr_grassl_p) = GO x (fraction peat soil within GO) x (5.3 - 4.7) (Eq 2.3.10)

These 'extra' N_2O emissions are added to the emissions of equations 2.3.1 to 2.3.8. By multiplying by 44/28 the total N_2O farm emission is obtained in kg N_2O per year.

Table 2.3.4 *The soil-related N inputs and N_2O emission factors. Values belonging to Cf and Of are based on Velthof & Mosquera (2011), values belonging to An are from Velthof et al. (1996), other values are assumed to be the same as those from Cf and Of or are from other literature sources.*

Inputs (kg N y^{-1}) a)	Code	Description	Emission factors (EF) b) (g N_2O-N (g N input) $^{-1}$	
			IPCC (2006)	Values in BEN k)
Volatilization ('off-farm’)	Vol	Total N loss due to volatilization	0 , 01	0 , 01 (IPCC)
Leaching (‘off-farm’)	Lea	Total N loss due to leaching	0 , 0075	0 , 0075 (IPCC)
Chemical fertilizer	Cf	Applied chemical fertilizer-N	0 , 01	Grassland: 0 , 008-0 , 03 c) Cropland: 0 , 008-0 , 03 c, d)
Organic fertilizer	Of	Organic fertilization applied e)	0 , 01	Grassland: 0 , 003-0 , 01 c) Cropland: 0 , 013-0 , 02 c)
Excretion in the field	An	Excretion in the field (manure plus urine)	0 , 02	Grassland: 0 , 024-0 , 061 c)
Net organically fixed N	Cl	N fixed in crop residues of leguminous plants	0 , 01	Mix Culture f : 0 , 003-0 , 01 c, g) Monoculture: 0 , 013-0 , 02 c, g)
Crop / grass residues	Cr	Total input via crop / grass residues	0 , 01	Grassland: 0 , 003-0 , 01 c, g) Cropland: 0 , 013-0 , 02 c, g)
Input via soil organic matter decrease	Om	Net decrease in soil organic N on mineral soils	0 , 01	Grass-grass h) : 0 , 003 g) Perm. arab.,: 0 , 013 g) Grass-arable: 0 , 008 i)
Extra mineralization in peat soils	Pt	Decrease of soil organic N on peat soils	8 kg N_2O-N ha^{-1} y^{-1}	4 , 7 kg of N_2O-N ha^{-1} j^{-1} j)

a) Inputs are determined per land use type (grassland or arable land) and, if possible, per soil type.

b) EF’s are based on total inputs including any ammonia emission in the field.

c) The first value applies to mineral soils, the second value to organic soils.

d) Value is assumed to be equal to that of grassland.

e) Value applies to low-emission application (with respect to ammonia volatilization).

f) Mixed culture applies to grass-clover mixtures, monoculture applies to arable cultivation of leguminous plants.

g) Values are assumed to be equal to those of organic fertilizer application on grassland or arable land.

h) Grass-grass refers to permanent grassland or re-sowing of grassland; perm. arab. refers to permanent arable cropping, and grass-arable to arable farming and grassland in rotation.

i) Values are estimated by averaging the values for organic fertilizer application on grassland and arable land.

j) Value is based on a net decrease of 235 kg N ha^{-1} y^{-1} due to oxidation of soil organic matter and an emission factor of 0.02 (source: NL protocol for reporting N_2O emissions (NIR, 2014), based on on Kuikman *et al.* (2005).

k) The values within the uncertainty range as published by the IPCC: 0 , 007-0 , 06 for excretion in the field, 0 , 003-0 , 03 for other inputs and 2-24 for N_2ON emissions from cultivated organic soils in the temperate climate zone.

2.3.2.3 Emission of N_2O from manure storages

2.3.2.3.1 Dairy cattle

This section describes the method of calculating the average annual N_2O emission from the manure storage facilities of a dairy farm in the Netherlands. This emission is initially calculated in kg N_2O-N per farm. The following manure management systems are distinguished:

- Liquid 'stable manure' in storage (slurry).
- Solid 'stable manure' in storage (solid manure).

Slurry is considered to be stored in a manure pit under the stables and in manure storage facilities outside the barn. Solid manure is considered to be stored in the stable (for example, deep litter) and in an outdoor storage facility (manure heap).

The method of calculation in the context of BEN is largely based on national monitoring protocols. These protocols describe the methods and processes for the determination of the emissions, including activity data and emission factors. These have been published by the Ministry of Infrastructure and the Environment (IenM). This protocol falls under IPCC categories 4B11 and 4B12: N_2O manure management (www.agentschapnl.nl/ programs-regulations / monitoring protocols). This protocol is limited to N_2O emissions from manure produced in the barn, temporarily stored and/or treated/processed and then removed. Nitrous oxide emissions from manure excreted on pasture are discussed in the previous section 2.3.2.2.

The emission of N_2O from animal manure during storage and treatment depends on the N and C content of the manure, the storage time of the manure in storage and the method of treatment. During storage, the manure often becomes low in oxygen, which inhibits nitrification and keeps denitrification low. Nitrification is the process of converting ammonium (NH_4^+) into nitrate by bacteria under oxygen-rich conditions. Nitrous oxide can be formed as a by-product, especially if nitrification is inhibited by a lack of oxygen. No organic matter is required for nitrification. Denitrification is the process by which bacteria convert nitrate (NO_3^-) into the gaseous nitrogen compound N_2 under anoxic conditions , with the by-product N_2O. In this process organic matter is used as an energy source. The N_2O emission from solid manure is higher than the emission from liquid manure, because nitrification hardly occurs in liquid manure due to a lack of oxygen.

The emission of N_2O from animal manure is calculated as follows:

$$N_2O_{(Dmm)} = \left[\sum_S \left[\sum_T \left(Nexcretion_T * MS_{(T,S)}\right)\right] * \ EF_{(S)}\right] * \frac{44}{28}$$

Where,

$N_2O_{(Dmm)}$: N_2O emission from manure management systems in kg.

$Nexcretion_{(T)}$: Total N excretion per animal category *T* in kg (with *T* = dairy cattle, young stock or (total) other ruminants). This N-excretion is derived from BEX (section 2.1), but is not reduced by the gaseous N-losses from the stable and storage, nor is it corrected for manure import and export. According to IPCC conventions, the N_2O emissions from manure storages only relate to manure produced on the farm itself.

$MS_{(T, S)}$: fraction of total N excretion per animal category T in manure management system S.

EF (S): emission factor for the defined manure management system S in kg N_2O-N / kg N excreted manure.

44/28: conversion factor from kg N_2O-N to kg N_2O

S : manure management systems: liquid manure system and solid manure system.

The amount of N in manure refers to the gross amount of N in manure, i.e. not reduced by gaseous N losses from the stable and storage. This methodology corresponds to the IPCC method (IPCC, 2006). This means that the total amount of manure N produced is multiplied by the emission factor without deducting ammonia and other gaseous N losses.

The amount of manure produced is determined using the 'Tier 3' method (i.e. country-specific). Country-specific ('Tier 3') values are also used for the emission factors . The calculations are made according to the National Ammonia Emission Model (NEMA; Velthof *et al.* , 2012; Van Bruggen *et al.* , 2017). In addition to NH_3 , the NEMA model estimates emissions of N_2O, NO and N_2 from stables and storage facilities (Tables 2.2.2 and 2.2.3).

The emission factors use the default values of IPCC (2006) (Table 2.3.5).

Table 2.3.5 *Emission factors (EF_S) per manure management system in kg N_2O-N / kg N excreted manure.*

Manure management system	Emission factors in kg N_2O-N / kg N excreted manure in the stable
Liquid manure	0.002
Solid manure	0.005

Source: IPCC, 2006.

2.3.2.3.2 Other ruminants

For the 'other ruminants', the fixed net manure-N production (Table 2.1.7) is first converted to gross manure-N production based on the ratio net / gross (Table 2.2.1), similar to the calculation of the TAN production. Then it is calculated how much N_2O-N is formed, using N_2O-N emission factors (Table 2.3.6).

Table 2.3.6 *Emission Factors (EF_S) per animal category in kg N_2O-N / kg N excreted manure.*

	Emission factors in kg N_2O-N / kg N excreted manure in the barn	
Animal category	Liquid manure	Solid manure
Breeding bulls> 1 year (cat. 104)	0.002	0.005
Pasture and suckler cows (cat. 120)	0.002	0.005
Nursing calves, rosé or red meat (cat. 115)	0.002	0.005
Rosé calves, 3 months - slaughter (cat. 116)	0.002	0.005
Rosé calves, 2 weeks - slaughter (cat. 117)	0.002	0.005
Red meat bulls, 3 months - slaughter (cat. 122)	0.002	0.005
Breeding sheep (cat. 550)	0.002	0.005
Meat sheep, <4 months (cat. 551)	0.002	0.005
Other sheep,> 4 months (cat. 552)	0.002	0.005
Milk goats (cat. 600)	0.01	0.01
Rearing and meat goats, <4 months (cat. 601)	0.01	0.01
Rearing and meat goats,> 4 months (cat. 602)	0.01	0.01
Ponies (cat. 941)	0.002	0.005
Horses (cat. 943)	0.002	0.005

2.3.2.3.3 'non-ruminants'

Fixed nitrous oxide emissions, which do not depend on the ration composition , are used for the category 'non-ruminants'. These depend on the animal type and the type of stable, as follows:

Nitrous oxide emission (kg N_2O) = GAD x nitrous oxide (kg N_2O-N per animal) * 44/28

where:

GAD = average number of animals present (from the input data)
Nitrous oxide = emission in kg N_2O-N per animal (Table 2.3.7)

Table 2.3.7 *Gross N excretion (kg N per animal place) and emission factors of N_2O-N (EF_{N2O}) and of the other gaseous N losses (other than NH_3 (EF_{notNH3})) in kg N per 100 kg gross N-excretion for slurry (DM) and for solid manure (VM).*

Animal category_oms	Gross N excretion (kg N per animal place)	EF_{notNH3}, DM	EF_{notNH3}, VM	EF_{N2O}, DM	EF_{N2O}, VM
Farrowing sows	36.6	2.4	3.5	0.2	0.5
Dry and pregnant sows	17.85	2.4	3.5	0.2	0.5
Weaned piglets	3.4	2.4	3.5	0.2	0.5
Fattening pigs	10.9	2.4	3.5	0.2	0.5
Laying hens	0.726	1.2	0.7	0.1	0.1
Broilers	0.498	1.2	0.7	0.1	0.1
White meat calves	10.58	2.4	3.5	0.2	0.5

2.3.2.4 Other gaseous N-losses, other than NH_3-N and N_2O-N

In the previous paragraphs it was indicated where and how much N is lost as ammonia, as nitrate and as nitrous oxide. The remaining difference between input and output of N is attributed to stock changes on the farm ((synthetic) fertilizer, feed, livestock) and in the soil (especially organic N) and gaseous losses other than NH_3-N and N_2O-N. It is assumed that these 'residual gaseous N losses' do not only occur from the soil, but also to a small extent from the stable and manure storages and from silage pits. These are losses in the form of N_2 and NO_x .

In Figure 1.3, the item 'conserved roughage and by-products' is shown. It is the sum of the harvested roughage, the balance of sold and purchased roughage (positive value if more is sold than bought) and by-products (adjusted for stock changes). The remaining gaseous N losses from these silages are calculated at 3, 1 and 1.5% for ensiled grass, maize (WPCS, WECS and CCM) and additional roughage including wet by-products, respectively (Table 1.1).

The remaining gaseous N losses from housing and storage are calculated as the difference between other gaseous N losses according to Tables 2.2.6 (other ruminants) and Table 2.2.9 (non-ruminants) and the nitrous oxide losses according to Table 2.3.6 (other ruminants) and Table 2.3.7 (non-ruminants), with losses always being based on the sum of the gross amount of 'stable manure', the manure exported and the manure imported (corrected for stock changes). With regard to 'non-ruminants', it is assumed that, similar cattle, nitrous oxide and other gaseous N losses (Table 2.3.7) occur from stables and storage, besides ammonia (Table 2.2.8).

2.3.3 Comments on BEN

It has been decided not to wait with introducing ANCA until every conceivable type of farm and, within it, every N-flow can be calculated. ANCA, therefore, is not yet suitable for:

- Accurately evaluating the crop-specific N efficiencies in the grassland and arable land phase of rotation systems because the N yields do not distinguish between rotation and continuous cropping, and the output items of grazing, cutting and harvesting losses do not yet exactly match with input items assigned to the subsequent crops in rotation,

- In ANCA, the mineralization from peat soil with grassland is set at 235 kg N per ha per year. This number is taken from Kuikman *et al.* (2005). In previous publications, the same mineralization with reference to Van Kekem (2004) has been estimated at 160 kg N per ha per year. It is recommended to to do further research on estimating N loss from peat soils,
- With regard to nitrate leaching, it is noted that the relationship between the calculated N surplus and the nitrate N concentration in the upper groundwater or near surface water is derived from observations on many farms and over many years. The average of these observations was then determined. Even within the same soil type (peat, clay, sand), dewatering class (wet, dry) and type of land use (grassland, arable land), however, there is a very large spread between farms and between years. That dispersion is due to the fact that the items mineralization and fixation are not in balance each year, precipitation surpluses vary, and also denitrification depends on more factors than mentioned here. From that point of view, it is debatable to assess farm performance based on only one or a few years, and the predicted nitrate concentrations should therefore be interpreted as an indication of the nitrate concentration under average conditions for the soil type, dewatering class and land use concerned,
- With regard to the emissions of N_2O from the soil, the following should be noted. These emissions vary greatly in space and time, which often requires many measurements. Total annual emissions are usually determined based on a limited number of measurement periods (e.g. part of the day and a number of days in the year) and by interpolation total year-round emissions are estimated. Partly as a result of this, there is a large uncertainty and room for improvement of the calculation method and the determination of the emission factors and other parameters. In 2013, national and international experts were invited to talk about improvements and alternative methods (workshop 7-03-2013, Wageningen). The methodology followed in BEN (based on 'Tier 1' of the IPCC (2006)), provides a basis for easily incorporating future improvements, either or not in consultation with international experts. Based on a limited literature review, the following aspects in particular appear to be eligible for future adjustments:
  - N_2O emission from unfertilized fields. The Velthof & Mosquera database (2011) provides a large number of field studies for determination of the emission from unfertilized fields.
  - Effect of average soil moisture conditions. Major effects are to be expected from the average soil moisture conditions of mineral soils and peat soils. Literature shows a relationship between the average groundwater level and the N_2O emissions from peat soils in the Netherlands, which could be used in a subsequent version of BEN. Obviously, this does increase the data requirements in BEN.
  - Grassland renewal. Tests have shown that grassland renewal also changes the emission factors of the fertilizer applied compared to the situation without renewal. Through additional literature review adjusted emission factors can be determined.
  - Changes in organic matter content. BEN takes into account the extra N_2O production that results from peat mineralization, but ignores the N_2O production that would occur if the organic matter content of a mineral soil decreases. This should be taken into account in the future version of BEN.
  - Balance method. An alternative calculation method is based on the idea that the N_2O emission can be described as a fraction of the total denitrification, or of soil N surplus. In literature examples have been found that used this method. However, more literature research and consultation with experts is needed to determine reliable emission factors for this method.

2.4 BEP: farm-specific P flows

2.4.1 Introduction

BEP aims to calculate how much P (P_2O_5) is ingested by ruminants ('through the mouth ') and, possibly, geese, and how much is harvested by machines ('leaving the field') in the form of roughage (fresh grass), silage grass and maize (WPCS, WECS and CCM), alfalfa, field beans, WPS) or marketable arable crops. This key figure provides insight into how much P must be added in the form of manure and / or fertilizer to ensure that input and output are in balance.

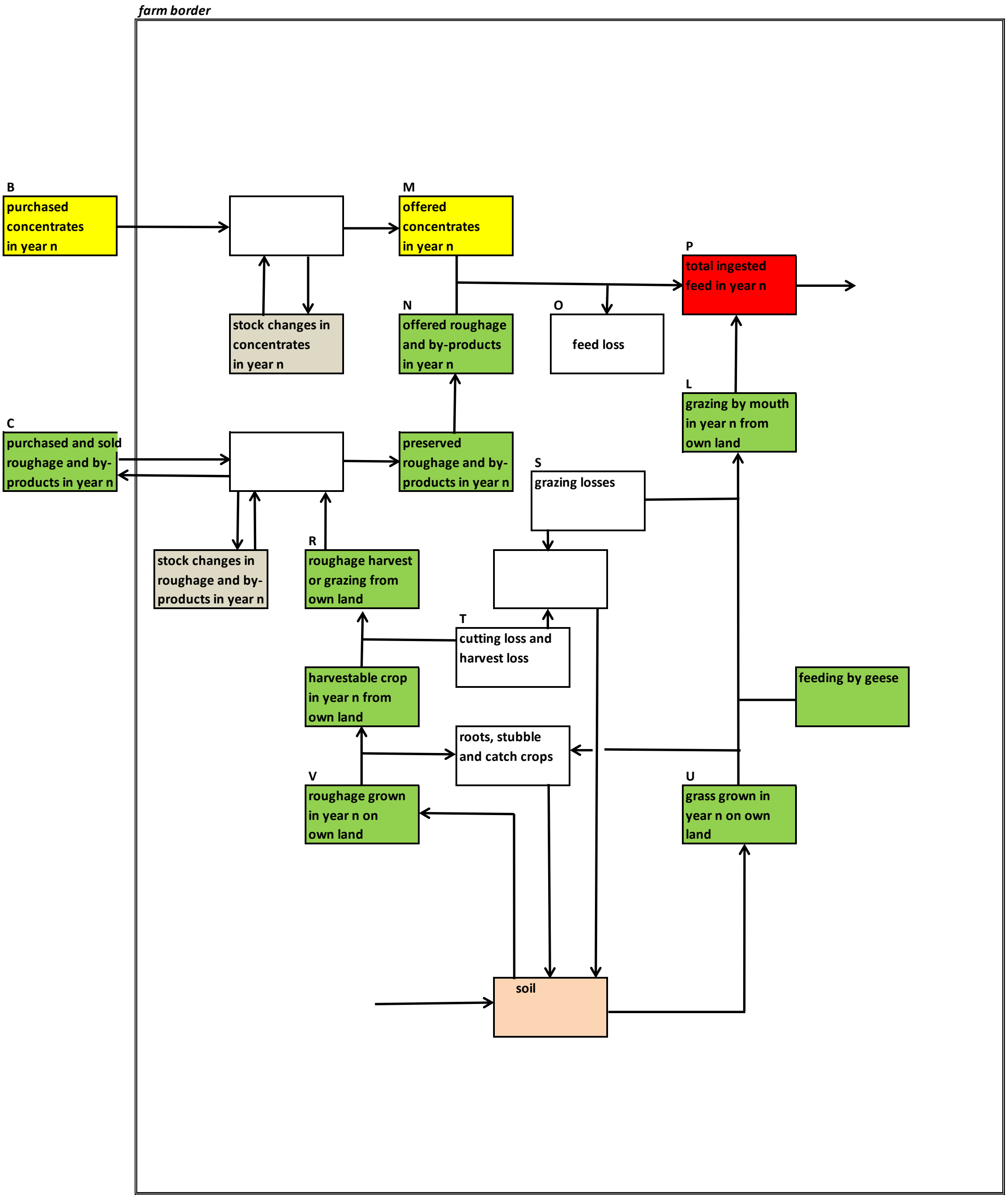

Figure 2.4.1 *Nutrient flows involved in calculating the amount of P harvested by machines and animals from own land on a dairy farm without an arable branch.*

2.4.2 Calculation method

In the context of BEX, the total VEM requirement of the dairy herd on the farm is calculated based on herd composition and production. A breakdown is made into purchased feeds (concentrates, purchased roughage) and self-cultivated roughages (pasture grass, silage grass, maize silage (WPCS, WECS and CCM), lucerne, field bean, GPS). By multiplying each of these feeds by their farm-specific P / VEM ratio, it is calculated how much P (kg P_2O_5) has been ingested from own feed and how much has been harvested by grazing ('mouth') or machines . Figure 2.4.1 clarifies this.

P intake from own feed = total P intake - P intake from purchased feed (Eq 2.4.1)

where:

P intake from own feed = P in roughage harvested by mouth or machine -
P feed leftovers $_{ownfeed}$, (Eq 2.4.2)
⟷ P harvested in roughage by mouth or machine = P intake from own feed + P feed leftovers $_{ownfeed}$

and:

P intake from purchased feed =

P in purchased feed - P stock change - P feed leftovers $_{purchased\ feed}$ (Eq 2.4.3)

It is assumed that the amount of feed leftovers is 2 to 5%, depending on the type of feed (Table 1.1), and is calculated as follows:

Feed leftover-P = 0.05 x (P intake from conserved grass and silage maize /
(1- 0.05)) + 0.03 x (P intake from other self-cultivated roughage and wet by-products / (1-0.03))
+ 0.02 x (P intake from concentrates, compound feed and milk products / (1- 0.02)) (Eq 2.4.4)

Furthermore, it is assumed that no P is lost during the conservation of purchased or self-cultivated roughage. The sum of the P in roughage harvested by mouth or machines and P in purchased feed ends up in either stocks, or in the manure of the dairy cattle, or in feed leftovers, or in milk and meat of dairy cattle:

P in roughage harvested by mouth or machine + P in purchased feed corrected for stock changes
=
P in manure (including feed leftovers) + P in milk and meat from dairy cattle (Eq 2.4.5)

The amount of P in roughage harvested by mouth or machine is corrected for indicated stock changes and purchased feed. Since a model deviation arises from the BEX calculation, the stock change and purchased feed are corrected with a so-called 'roughage factor'. This factor corresponds to the ratio between P intake from grass silage and maize silage according to the BEX module, and the P intake from own grass silage and maize silage according to data entry. This entry is equal to P stock changes in grass silage and corn silage plus the existing stock of grass silage and corn silage. The consequence of this correction is also that the amount of P in roughage harvested by mouth or machine (only the proportions of grass silage and corn silage) changes. In a formula:

factor_purchase_mutation = (BEX_Popn_gksm_mlk + BEX_Popn_gksm_ovg) /
(Stock_Pverbr_gksm * (1-PcFeedlossRoughage / 100))

factor_ purchase_mutation = Factor for the ratio between P import (entered by user) and P stock mutation in the form of grass silage and silage maize and the P intake according to BEX

BEX_Popn_gksm_mlk = P intake of dairy cattle from grass silage and silage maize

BEX_Popn_gksm_ovg = P intake of other ruminants from grass silage and silage maize

Stock_Pverbr_gksm = P use calculated from declared stocks (start + change - end)

PcFeedlossRoughage = Percentage of feed leftovers in forage

Here it is assumed that, unlike with N, no significant losses of P by air occur. Furthermore, the supply to the soil and the discharge from the soil are balanced if:

P in fertilizer applied to land for roughage cultivation + P in purchased feed for the dairy herd corrected for stock changes = P in milk and meat of dairy cattle ↔

P in purchased feed for the dairy herd corrected for stock changes =
P in milk and meat of dairy cattle - P in fertilizer applied to land for roughage cultivation. (Eq 2.4.6)

Substitution of equation Eq 2.4.6 in Eq 2.4.5 gives:

P in roughage harvested by mouth or machine + (P in milk and meat of dairy cattle) - P in synthetic fertilizer applied to land for roughage cultivation =

P in dairy manure (including feed leftovers) + (P in milk and meat of dairy cattle) ↔

P in manure from dairy cattle (including feed leftovers) + P in synthetic fertilizer applied to land for roughage cultivation = P in roughage harvested by mouth or machine (Eq 2.4.7)

This means that there is equilibrium fertilization for the land used for the cultivation of the roughage if the P supply via (synthetic) fertilizer applied to land for roughage cultivation is the same as the amount of P in roughage harvested by mouth or machine.

Based on the ratio of the amount of stock increase from own grass (production grassland and natural grassland separately) and maize (grass products, intake of pasture grass, maize silage (WPCS, WECS and CCM), other silage (lucerne, field beans, GPS); see BEX), a derived P yield from grassland (production grassland and natural grassland separately), maize land and other roughage is determined. For the amount P from grassland ($P_{grassland}$) the following applies:

$P_{grassland}$ harvested by mouth or machine = P in roughage harvested by mouth or machine /
($P_{cut\ grass} + P_{pasture} + P_{maize\ silage} + P_{other\ roughage}$) * ($P_{cut\ grass} + P_{pasture}$) (Eq 2.4.8)

with:

$P_{cut\ grass}$ = the amount of P in own grass silage or fresh grass,

$P_{pasture}$ = the amount of P in grazed grass including feeding by geese (see section BEN),

$P_{maize\ silage}$ = the amount of P in own maize silage, and

$P_{other\ roughage}$ = the amount of P in silage pits with other own roughage.

For the amount P from maize land the following applies ($P_{maize\ land}$):

$P_{maize\ land}$ harvested by machine = P in roughage harvested by mouth or machine /
($P_{cut\ grass} + P_{pasture} + P_{maize\ silage} + P_{other\ roughage}$) * ($P_{maize\ silage}$) (Eq 2.4.9)

For the quantity P in other roughage from own land the following applies ($P_{other\ roughage}$):

$P_{other\ roughage}$ harvested by machines = P in roughage harvested by mouth or machine / ($P_{cut\ grass} + P_{pasture} + P_{maize\ silage} + P_{other\ roughage}$) * ($P_{other\ roughage}$) (Eq 2.4.10)

To determine on dairy farms with an arable branch and / or a 'non-ruminants' branch whether the supply of manure-P and synthetic fertilizer-P is in balance with the output of P in the form of milk and meat from dairy cattle and marketable arable products, the amount of cattle manure calculated in BEX (pasture manure, "stable manure ") should be added to the net amount of manure-P derived from the 'non-ruminant animal'-branch and the output of P in marketable arable crops should be calculated. The latter is done by requesting the number of hectares of the arable crops listed in Table 2.3.3 and the average yield of those crops in the respective year. Then the P-output is calculated by multiplying the yields by crop-specific standard values in Table 2.3.3. For arable crops not included in the table, it is assumed that they have a standard output of 60 kg P_2O_5 / ha. This figure is based on the average lump sum of a rotation consisting of 25% winter wheat, 25% ware potatoes, 25% sugar beet and five times 5% of summer barley crops, summer wheat, grass seed, grain maize and seed onions, each with assumed average yields such as stated by CBS (Statistics Netherlands) for the period 2009-2013, whereby only the main products are considered to have been removed. Thus:

P_2O_5 output from the arable branch (kg P_2O_5) = $\sum_1^n (\text{BOn x ((YHn x CPHn) + (YBn x CPBn)))}$,

With BOn = arable land area with crop n (ha), YHn = yield of main product of crop n (tons of fresh / ha), YBn = yield of removed by-product of crop n (tons of fresh / ha), CPHn = P_2O_5 content of main product (kg N / ton fresh) and CPBn = P_2O_5 content of by-product (kg N / ton fresh).

2.4.3 Comments on BEP

Previous research (Oenema *et al.* , 2011) indicates that there is a strong association between the P harvest calculated in this way, based on the estimated P intake from roughage from own land, and the actual amount of P harvested. The strength of association between these two parameters increases when the calculated amount of P harvested according to BEP is based on more years.

The figures used for field losses (grazing loss, cutting loss, harvest loss), conservation losses and feeding losses come from past research. It is advised to update these figures. The accuracy of the estimate of the amount of P harvested according to BEP also requires a more accurate estimation of silage pit densities. This research is currently executed.

The reliability of the BEP is lower when dairy farms have other branches, i.e. marketable arable production and other livestock. This is because P-input with 'non-ruminant animal'-manure and the P-output in marketable arable crops are based on standard values for manure production and P contents. Actual values will deviate from this.

2.5 BEC: farm-specific carbon flows and emissions of CO_2 equivalents

2.5.1 Introduction

One of the aims of the BEC of the KringloopWijzer is to estimate how much methane (CH_4) and carbon dioxide (CO_2) are released during the production of milk and meat. This is important because both, like nitrous oxide (N_2O), are greenhouse gases. The BEC module not only calculates the carbon (C) involved in the production of greenhouse gases CH_4 and CO_2, but also checks whether the C additions to the soil via crop residues and manure are in balance with the C consumption by soil life: the so-called organic matter balance. Crops absorb C from the air in the form of CO_2 and convert it into carbohydrates. On farms with livestock, animals convert the C in carbohydrates in roughage and concentrates into C in milk and meat (sugars, fats, proteins), into C in manure, into CO_2 and into methane (CH_4). During the storage of 'stable manure', part of the manure C is further converted into CO_2 and CH_4. The remaining part of the C in 'stable manure' is added to the soil together with the C in pasture manure, and the C in crop residues, in catch crops, in pasture, mowing and harvesting losses, and in feed losses. Soil life uses this C as food and thereby produces CO_2. If the additions of C to the soil are greater than the C consumption by the soil life, the organic matter content of the soil increases, and if the C consumption exceeds the addition, the organic matter content decreases. The compounds that make up this organic matter also contain N and P, besides C. The ratio between the three varies but is roughly (C: N: P) 96: 8: 1 (Kirkby *et al.* , 2011). This means that there are limits to the extent to which organic matter contents can (continue to) decrease without N and P also being released, but also that with (continued) increase in organic matter levels, net fixation of N and P occurs. These N and P are therefore not available for crop growth, but also cannot be lost to the environment. In this sense, the three cycles are linked via the soil, similar to the linkage via the composition of crops. Since organic matter in the soil consists of approximately 58% C (Anonymus, 2014), a fixation of 1000 kg of organic matter per ha (i.e. an increase in the organic matter content in a soil layer of 25 cm by approximately 0.03 percentage points) corresponds to approximately 580 kg C (2127 CO_2), 48 kg N, and 6 kg P (14 kg P_2O_5).

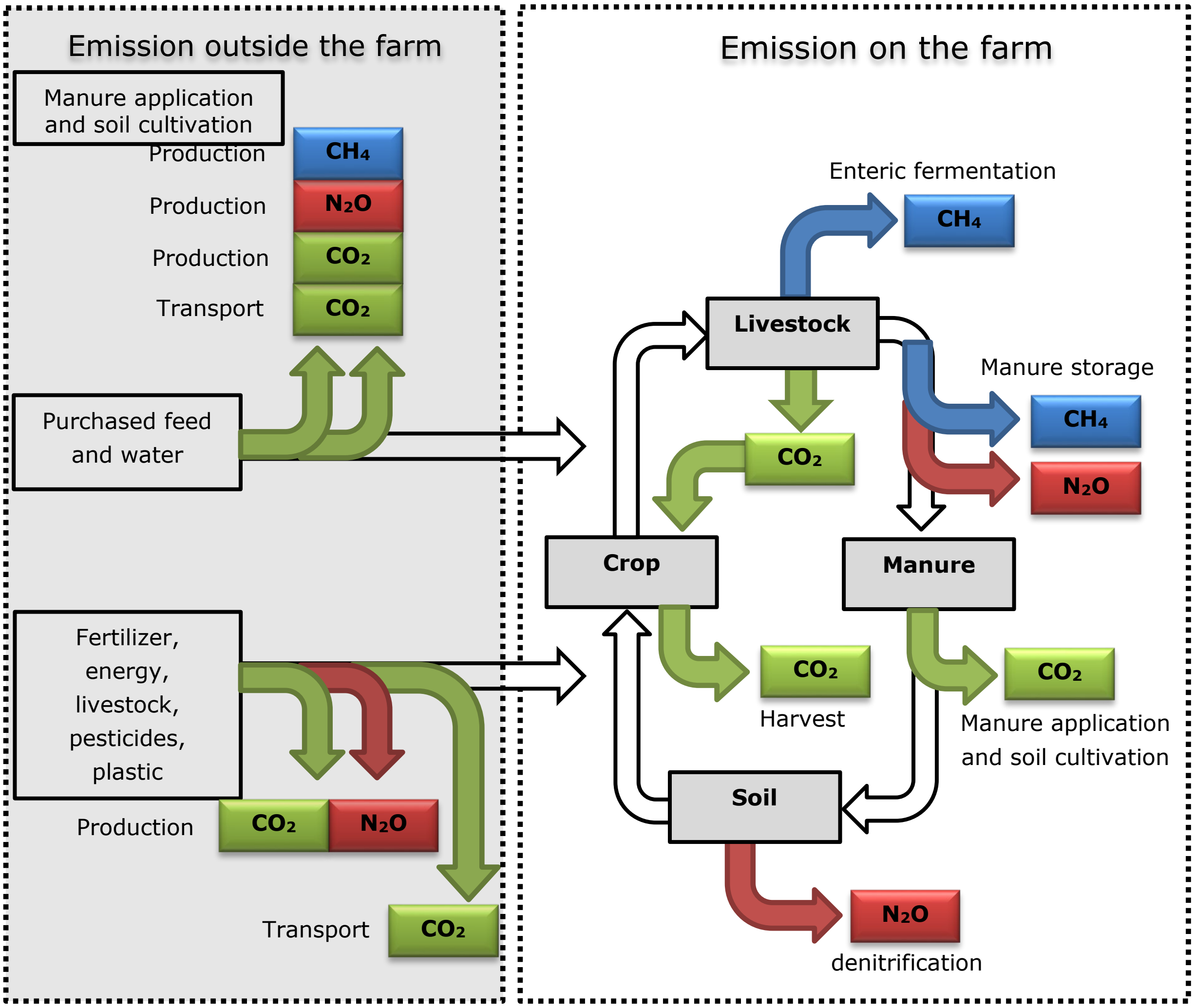

Figure 2.5.1 *Simplified scheme of greenhouse gas emissions on the dairy farm.*

In 2018, the European Commission adopted important rules for calculating greenhouse gas emissions from products. The rules are based on the Life Cycle Analysis (LCA). They are about the emissions associated with all inputs and processes required throughout the production chain to make a product.

This means that the BEC calculation differs from the other calculations because the BEX, BEA, BEN and BEP are limited to what happens on the primary farm.

The chain approach of the BEC means that the emissions must also be calculated for the following components:

- The production of purchased feed;
- The production of all inputs to the farm, such as fuels, fertilizers and machines;
- Machine use by contract workers;
- The land use change associated with the cultivation of crops outside the farm.

The calculation rules are described in the 'Product Environmental Footprint Category Rules' (PEFCR) for separate products. They include regulations on:

- Which categories should and should not be included;
- The use of primary data (from the farm itself) and indicate when secondary data (statistical data) are allowed;
- Expressing methane and nitrous oxide in CO_2 equivalents. These are explained below;
- Including emissions from Land Use Change in the production of crops. This is further explained in section 2.5.4;
- Allocating emissions to milk and live weight on the dairy farm. This is further explained below;
- The calculation of emissions of methane, nitrous oxide and carbon dioxide are in line with IPCC rules, particularly for methane and nitrous oxide, but leave room for the use of national emission factors. The emission calculations are described in the various parts of this report;
- Reporting of emissions. The PEFCR distinguishes the following categories: a) emissions from fossil sources; b) emissions from biogenic sources and c) land use and land use change. ANCA does not yet make this subdivision.

Detailed information can be found in PEFCR guidelines (2018a, b, c).

2.5.2 Expressing methane and nitrous oxide in CO_2 equivalents

To be able to sum different gases, the greenhouse effect of CH_4 and N_2O is expressed in CO_2 equivalents: 1 kg CH_4 from biological processes corresponds to 34 kg CO_2 , 1 kg CH_4 from fossil fuel corresponds to 36.75 kg CO_2 and 1 kg N_2O corresponds to 298 kg CO_2 (PEFCR, 2018a).

2.5.3 Allocation of emissions to milk and culled animals

Allocation of emissions occurs in processes where multiple products are created. Calculation rules in LCA and the PEFCR indicate that allocation should be avoided if possible. Therefore, the calculation in ANCA takes place in two steps:

Step 1
In this step, only the emissions for dairy cattle are included. The emissions that can be clearly calculated and / or measured separately, are separated into dairy cattle (including young stock) and other animals. This means that, for example, only the energy and feed consumed by the dairy cattle are included, and that if, for example, half of the maize silage is exported, only half of the emissions associated with the cultivation of maize silage is included for dairy cattle.

Step 2
In this step, the remaining emissions from the dairy cattle must be allocated to the production of milk and the live weight of culled animals. A formula is used for this:

Milk allocation factor = 1 - 6.04 * Production_Live weight / Production_FPCM, with:

Production_Live weight = net removal of kg animals (only live animals) and

Production_FPCM = production of kg fat and protein corrected milk [kg milk * (0.2534 + 0.1226 * Fat% + 0.0776 * Protein%)], and
Allocation factor meat = 1 - Allocation factor milk

The CO_2 emission in g CO_2 -eq per kg FPCM can now be calculated as follows:

CO_2 emission milk = kg CO_2 equivalents emission dairy cattle / 1000 * Allocation factor milk / Production FPCM

2.5.4 Calculation of the emission of land use change

The PEFCR Guideline provides clear rules on this. The calculation is strongly based on the method as developed in the PAS2050: 2011 (BSI, 2011) and further developed in the supplement (PAS2050-1: 2011; BSI, 2012). In turn, the PAS calculation is based on calculation methods used in IPCC reporting. The IPCC calculates the total emissions from land use change, the PAS2050 calculates how these are allocated to crops per country. The calculation of these emissions (Blonk, 2019) is included in a tool that is part of FeedPrint / Agrifootprint (Vellinga *et al.* , 2013).
The PEFCR prescribes that this calculation method may only be overridden if certificates are available showing that (for example) soy has been grown in locations where land use change is no longer the case. In the absence of certificates, the standard procedure must be followed.

2.5.5 Sources of emissions

Methane is released during digestion of feed in -particularly- ruminants and from manure. Also methane can be emitted during the cultivation or processing of purchased feed ingredients. This is the case, for example, with rice products and palm kernel meal.

Carbon dioxide emissions are related to the use and, if any, the generation of energy on farms. This is because CO_2 is released when fossil energy is used, and CO_2 emissions are avoided when the use of fossil energy is avoided. Energy consumption occurs, for example, in the production of milk. This concerns energy for, for example, cooling, heating and the use of machines in the field and yard. Energy can be consumed in the form of fuels (diesel, gas, propane, fuel oil) or in the form of electricity. Gas can be 'made' on the farm itself or imported to the farm and, when imported, be based on fossil or renewable sources. In addition to energy consumption on the farm, raw materials are often imported to the farm for which (fossil or renewable) energy was used for production outside the farm, such as purchased fertilizers and (concentrate) feed. In addition, the production and transport of somewhat smaller farm inputs such as water use, purchased animals, litter, pesticides and plastic are taken into account.

Nitrous oxide is emitted in all processes where N is used. The relevant calculation rules are discussed in detail in section 2.3.

ANCA has two ways of calculating energy consumption:
- Registration: from meters and bills, split into dairy cattle and other farm activities, and
- Calculation of standards based on additional information obtained.

Methods for the calculation of the standards is described in detail in the following sections.

Non-ruminant livestock is not included in the farm calculation because only part of the data is available. Nothing is known about the supply of, for example, feed for this branch in ANCA.

2.5.6 Calculation methods

2.5.6.1 Emissions from rumen enteric fermentation (enteric methane)

With regard to enteric methane emissions, ANCA is currently limited to ruminants ('ruminants'). The methane emission resulting from fermentation in the gastrointestinal tract represents approximately 75-

80% of the total methane emission on dairy farms. The rest comes from the manure storage. In the calculation, a distinction is made between dairy cattle (including young stock) and other ruminants.

Dairy cattle (including young stock)
The CH_4 emission from rumen enteric fermentation in dairy cattle is calculated according to the most accurate level permitted by the IPCC: the Tier 3 level. This Tier 3 method offers both the most accurate estimate of enteric CH_4 emissions and most management options to reduce (mitigate) methane emissions. The Tier 3 method is based on the fact that the methane emission depends not only on the level of rumen fermentation (i.e. kg feed ingested and fermented), but also on the particular type of feed material that is ingested and the fermentation conditions in the rumen (acidity). The nutrient composition and the degree of acidity in the rumen influences the composition (ratio) of fermentation products produced in the rumen: acetic acid, propionic acid, butyric acid and other volatile fatty acids. With shifts in the ratio of these fermentation products also the amount of hydrogen varies that is produced in the rumen from fermented feed. Because almost no hydrogen disappears from the rumen (<1%, as shown in experiments), it is assumed that all hydrogen is converted into methane.

The Tier 3 method uses a dynamic mechanistic simulation model to estimate the emission factor (EF) of each of the different feeds (or a total ration) based on the chemical composition and digestion characteristics of the specific feed ingredient. This factor (in g CH_4 per kg DM feed) is then used to calculate the methane emission. The calculation applied in ANCA is described below. This is based on Šebek & Bannink (2019).

The EF values for the different feed ingredients take into account the share of maize silage in the roughage part (= fresh grass, grass products and maize silage products) of the ration (based on kg DM). The total of all EF values of all feed ingredients are referred to as 'EF lists' in this report. Because differentiation is made based on the share of maize silage in the roughage part of the ration, EF lists have been derived for rations with different shares of silage maize (0%, 40% and 80%) in the roughage part of the ration (see Appendix 1). A good estimate of the enteric methane emission for every dairy cattle ration with a share of silage maize between 0% and 80% can be done by interpolation with the 3 EF lists for the rations with 0%, 40% and 80% maize silage in the roughage. This approach is also appropriate for older young stock feeding on roughage. It is therefore in line with the ANCA approach to calculate rations at the herd level.

The calculation is as follows. First, the share of maize silage in the roughage part of the ration is calculated (% of the dry matter intake):

SUM kg DM from roughage = total amount of dry matter from roughage
% silage maize in roughage = 100 * (kg DM maize silage / SUM of kg DM from roughage)

Roughage is defined as the sum of fresh grass, grassland products and maize silage products.

Subsequently, for three levels of the share of maize silage products in the total dry matter supply from roughage of dairy cattle (0%, 40% and 80%), the methane emission (g CH_4 per kg dry matter) is calculated for the entire ration. This concerns the sum of the emissions of the individual feed components. For many feeds this is a fixed number per kg of dry matter (Appendix 1), but for conserved grass and maize silage products it is calculated based on the specified feed values (energy, CP and ash, g / kg) and for compound feed it is calculated on based on the crude protein content (CP, g per kg) in the product. The formulas used for this are explained below.

Then the total emission, called CH_4 _E feed (g CH_4 / kg DM), is estimated via interpolation based on the share of maize silage in the roughage part of the ration:

- If the calculated % of maize silage is between 0% and 40%, then interpolate with the EF lists 0% and 40%

- If the calculated % of maize silage is between 40% and 80%, then interpolate with the EF lists 40% and 80%

After that, a correction must be made for the feed intake level (total dry matter intake). This assumes an average change in the calculated methane emission per kg DM (based on EF lists) of 0.21 g methane per kg DM compared to the average feed intake of 18.5 kg DM per animal per day for the average Dutch dairy cow:

CH_4 _EFcorIntake (g CH_4 / kg DM) = 0.21 x (DM intake per day per LU - 18.5).

This leads to the so-called CH_4 _EF base:

CH_4 _EF base (g CH_4 / kg DM) = CH_4 _EF feed - CH_4 _EFcorIntake.

Finally, adjustments still have to be made for young stock. The methane emission from young stock differs from the methane emission from dairy cattle for two reasons, namely feed intake level and a different emission per kg DM as a result of a different rumen effect. By calculating per LU, differences in feed intake level are corrected (see also section 1.2). With regard to differences in rumen effect, the report by Šebek & Bannink (2019) shows that this relates to animals that do not yet absorb sufficient roughage, with an age limit of 3 months being proposed as the criterion. The enteric methane emission from these young calves was found to be about 1/3 of the methane emission from a dairy cow. It follows that with the method described above, an overestimation is made when calculating the CH_4 emissions at the herd level of the methane emissions from young calves. The following calculation rules prevent this overestimation.

The fraction of young calves (FJK) is defined as:

FJK = LU calves from 0-3 months / LU total (ie all cows, heifers and young stock together)

The methane emission factor of the ration (CH_4 _EF ration) is calculated via the young calf correction as:

CH_4 _EF ration (g CH_4 / kg DM) = CH_4 _EF base x ((1-FJK) + (0.33 x FJK))

The CH_4 emission of the total dairy herd (CH_4 _ ration) is finally calculated as:

CH_4 _ ration = CH_4 _EF ration x DM intake of dairy herd

<u>Calculation EF for conserved grass and silage maize and compound feeds</u>
As indicated above, for conserved grass products and conserved maize silage, the EF values have been derived based on the energy (using the Dutch energy unit for lactation, 'VEM'), crude protein (CP) and crude ash (CA) content. The regression formulas used for this are shown below.

Conserved grass (g CH_4 / kg DM):
EF0% = 36.87 - 0.01425 * VEM - 0.0020 * CP - 0.0354 * CA
EF40% = 36.87 - 0.01425 * VEM - 0.0020 * CP - 0.0354 * CA
EF80% = 38.37 - 0.01425 * VEM - 0.0020 * CP - 0.0354 * CA
Minimum: VEM = 579, CP = 71, CA = 48, EF0 = 0.9 * 14.07, EF40 = 0.9 * 14.07, EF80 = 0.9 * 15.57
Maximum: VEM = 1012, CP = 265, CA = 337, EF0 = 1.1 * 25.17, EF40 = 1.1 * 25.17, EF80 = 1.1 * 26.67

Conserved maize silage (g CH_4 / kg DM):
EF0% = 67.51 - 0.04978 * VEM
EF40% = 66.61 - 0.04978 * VEM

EF80% = 65.31 - 0.04978 * VEM
Minimum: VEM = 807, EF0 = 0.9 * 13.57, EF40 = 0.9 * 12.67, EF80 = 0.9 * 11.37
Maximum: VEM = 1063, EF0 = 1.1 * 26.83, EF40 = 1.1 * 25.93, EF80 = 1.1 * 24.63
The above calculation rules for conserved grass products and maize silage differ from the proposed calculation rules in Wageningen Livestock Research report 986 (Šebek & Bannink, 2019). Here, the methane emission is calculated based on the NDF content (conserved grass) and NDF and starch content (maize silage). These parameters gave the best association with methane emission. From 2020, this will be included in ANCA. However, this is not yet the case in the 2019 version, because the NDF and starch contents have not yet been included in the ANCA central database. Therefore, in 2019 version the regression formulas are used as shown above based on VEM, CP and CA content. Although these formulas are suitable for representing the range in enteric CH_4 , they are less accurate than the formulas based on the NDF content. Also, the explanatory variables used do not fit well with the logic of the functioning of the rumen.

The regressions were performed on data from the 'Koeien en Kansen' project from 2010 to 2016 for which CH_4 was estimated as EF0%, EF40% and EF80% according to the calculation rules proposed in this report based on NDF. Subsequently, regression analyzes were performed with that data set with CH_4 (g per kg DM) as the variable to be explained and the content (in DM) of VEM, crude protein and crude ash as the explanatory variables. All 3 explanatory variables were found to contribute significantly.

For compound feeds, the EF is based on the CP content.

Compound feeds (g CH_4 / kg DM):
EF0% = 26.75 - 0.0414 * CP + 0.000061 * CP^2 (re in g / kg DM)
EF40% = 26.35 - 0.0407 * CP + 0.000059 * CP^2 (re in g / kg DM)
EF80% = 27.36 - 0.0433 * CP + 0.000067 * CP^2 (re in g / kg DM)
Minimum: CP = 100
Maximum: CP = 350

Other ruminants
Tier 2 is used for ruminants other than dairy cows and associated young stock. The Tier2 calculation for the methane emission assumes that a fixed percentage of the intake of gross energy is lost in the form of CH_4 . In the IPCC calculation rules, this methane conversion factor Y_M for North West Europe is set at 6.5% for dairy cattle rations. This percentage is used here.

The calculation is as follows. The gross energy intake can be estimated without knowledge of the digestibility of feeds by multiplying the amount of ingested feed in kg dry matter (DM) by the average gross energy value of 18.45 MJ / kg DM. This conversion factor is relatively constant for different ruminant rations and is also recognized as a default value by the IPCC (IPCC, 2006).

GE herd intake*	= DM herd intake • 18.45
CH_4 emission (in kg CH_4)	$= \frac{BEintake \bullet \boldsymbol{Ym}}{55{,}65} \bullet 100$

* Note: if concentrate feed intake is shown per kg of product, first convert to kg DM (rule of thumb: kg DM = kg product x 0.88).

Where:

GE = Gross energy, in MJ

DM = Dry matter intake of livestock, in kg

Y_M = Methane conversion factor, in ANCA 6.5% is used

18.45 MJ / kg = average gross energy content of a kg of DM cattle ration

6.5% = methane conversion factor for young stock in North West Europe (IPCC 2006)

55.65 MJ / kg = energy content of a kg CH_4

Based on the DM intake (kg / year) and the IPCC methane conversion factor Ym of 6.5% of the gross energy for the different categories of ruminants, sheep and goats, the lump sums of 'other ruminants' on the dairy farm have been calculated (in kg CH_4 per animal per year, Table 2.5.1).

For horses and ponies only IPCC Tier 1 emissions are available (IPCC, 2006) (Table 2.5.1).

Table 2.5.1 *Methane emissions (Tier 1) from 'other ruminants'.*

Category	Kg DM / jr	Y_M	CH_4 (kg / yr)	CH_4 (kg CO_2-eq / yr)
Breeding bulls,> 1 year (cat. 104)	3049	6.5%	65.7	2234
Pasture and suckler cows (cat. 120)	3433	6.5%	74	2516
Nursing calves, rosé or red meat (cat. 115)	659	6.5%	14.2	483
Rosé calves, 3 months - slaughter (cat. 116)	2050	6.5%	44.2	1503
Rosé calves, 2 weeks - slaughter (cat. 117)	1561	6.5%	33.6	1142
Red meat bulls, 3 months - slaughter (cat. 122)	2656	6.5%	57.2	1945
Breeding sheep, incl. Lambs (cat. 550)	469	6.5%	10.1	343
Meat sheep, <4 months (cat. 551)	62	6.5%	1.3	44
Other sheep,> 4 months (cat. 552)	312	6.5%	6.7	228
Milk goats (cat. 600)	851	6.5%	18.3	622
Rearing and meat goats, <4 months (cat. 601)	207	6.5%	4.5	153
Rearing and meat goats,> 4 months (cat. 602)	436	6.5%	9.4	320
Ponies (cat. 941)	1696	-	10.3	350
Horses (cat. 943)	2615	-	15.8	537

2.5.6.2 Emission of methane from manure

2.5.6.2.1 Principles

For CH_4 emissions from manure in stable and storage and in pasture the following two source categories are distinguished:

- Dairy cattle and associated young stock
- Other ruminants

The description of this protocol is based on the 'Tier 2' approach of IPCC (2006) and deviates from the methods described in national monitoring protocols, published by the Ministry of Infrastructure and the Environment (IenM). The national protocol falls under IPCC categories 4B1 to 4B9 and 4B13: 12-029 manure CH_4 (www.agentschapnl.nl/programmas-regelingen/monitoring-protocollen).

The methodology used here for the calculation of national CH_4 emissions differs from IPCC in that it assumes emission factors (EF) per kg of manure per animal category and per manure management system instead of the annual absolute amounts of CH_4 per animal (in kg per animal per year).

CH_4 emissions from animal manure arise from fermentation processes that occur in an anaerobic environment. This condition mainly occurs when liquid manure is stored in manure pits under stables and in manure storage facilities outside the house. With solid manure and pasture manure, the conditions are usually aerobic and the CH_4 production is relatively low.

Cattle manure can be divided into liquid 'stable manure', solid manure (also stable manure in the strict sense) and pasture manure. Because part of the dairy cows in the Netherlands is (partly) indoors during the grazing period in summer, in particular during milking and at night, 'stable manure' is also produced during the pasture period.

Any goats present are assumed to be kept indoors all year round and to produce solid manure. Sheep are other ruminants housed only in the lambing period. Solid manure is produced during this housing period. For horses and ponies a housing and grazing period is distinguished, producing solid manure in the housing period.

Liquid 'stable manure' is stored in the manure pit under the stables and in manure storage facilities outside the barn. Solid manure is stored inside the barn and in an outdoor storage. In both cases there may be anaerobic conditions, resulting in the emission of CH_4 . This emission can be reduced by preventing anaerobic conditions, for example by aeration or regular mixing and turning. However, the aerobic processes can lead to higher emissions of ammonia and nitrous oxide. The share of solid manure in the total manure production in the Netherlands is relatively small.

Pasture manure is produced on pasture during summer grazing. Because of mostly aerobic conditions, the CH_4 emissions from pasture manure are often relatively low. Besides anaerobic conditions, the formation of CH_4 in manure also depends on other storage conditions, such as the amount of manure already present (so-called 'inoculum') and the storage duration and temperature. The manure pit can be considered as a so-called accumulation system: there is a constant supply of manure into the 'reactor' (= manure pit) and the manure volume in the pit increases until the pit emptied for fertilization or until the moment that the manure is pumped to the outside storage. The CH_4 emission in such a system increases with an increasing amount of manure (= inoculation), a higher manure temperature and a longer retention time (Zeeman, 1994).

The CH_4 emission from manure also depend on the (chemical) composition of the manure, mainly the organic matter content.

2.5.6.2.2 Calculation method

The emission of CH_4 from animal manure is calculated as follows:

$$CH_{4Mest} = \sum_{S} \left[EF_{(T)} * N_{(T)} \right]$$

$CH_{4\ Manure}$: CH_4 emission from manure in kg

$EF_{(T)}$: emission factor for each defined animal category T in kg CH_4 per animal

$N_{(T)}$: number of animals per animal category T (dairy cattle, young stock and (total) other ruminants)

The emission factor per animal is calculated as follows:

$$CH_{4Mest} = \sum_{S}[EF_{(T)} * N_{(T)}]$$

EF $_{(T)}$: emission factor for each defined animal category T in kg CH_4 per animal

VS $_{(T)}$: the production of volatile solids per animal category in kg dry matter per animal per day

B $_0$: maximum methane production potential per animal category T in m ^{3} CH_4 per kg excreted VS

0.67 : methane density (kg / m^3)

MCF $_{(S)}$: methane conversion factor per manure management system in percentages of B_0

MS $_{(T, S)}$: fraction of total N excretion of each animal category T in manure management system S.

B_0
The maximum CH_4 formation is determined by the degradability of the organic components in the manure. B_0 is expressed in m^3 CH_4 / kg VS and the (default) values are derived from NIR (2014) (Table 2.5.2).

MCF $_{(S)}$
The MCF indicates the degree to which the amount of degradable substance is actually converted into CH_4 under certain conditions. IPCC provides default values for MCF per animal category depending on the average temperature in a region (Table 2.5.2).

VS $_{(T)}$
VS stands for volatile solids. This is the sum of VS from excretion of urine and faeces, and VS from feed residues and litter that end up in the manure.

The amount of VS excreted depends on the ration. The calculation is as follows (Zom & Groenestein, 2015):

VS in urine
The VS in urine is the amount of urea present. This is calculated from the amount of TAN nitrogen (N) in the urine (Urine-N). Almost all TAN-N is excreted in the form of urea ($CH4N_2O$). Based on the atomic weight of nitrogen and the molecular weight of urea, the excretion of VS with urine (VS_{urine}) is calculated as:

VS $_{urine}$ (kg) = Urine-N / 0.466 (= (14 * 2) / (12 + 4 * 1 + 14 * 2 + 16))

Urinary N excretion (kg N / year, TAN nitrogen) is determined in BEA.

VS in faeces
The VS excretion in faeces is calculated from the dry matter intake (kg DM) by the herd, the crude ash (CA) content in the dry matter (CA, g / kg DM), and the digestibility of the organic matter (DCOM,%). The dry matter intake and ration composition of the herd was determined via the BEX. This is calculated using standard dry matter contents from CVB tables (Appendix IV).
The data for the types of feed and grass products / maize silage products of the CA content come from entry in ANCA. The other CA contents and the DCOM values are values from the CVB tables (Appendix IV). In this way, a dry matter intake, CA content and DCOM value are obtained per feed ingredient.
For compound feed it is assumed that the DCOM is 85% and the CA content is 85 g / kg. These estimates are based on an average composition and the shares of main raw materials in compound feeds.

The net organic matter intake of each feed ingredient i is calculated as:

$$OM_{intake\text{-}i}\ (kg) = DM_{\ intake\text{-}i}\ (kg) \times (1000\text{-}\ CA_{\ i}\ (g\ /\ kg\ DM))$$

The total net organic matter intake (tot-OM $_{intake}$ in kg), of the total ration with n feed ingredients, is calculated as the sum of the organic matter intake of the individual feed ingredients:

$$\text{The tot-}OM_{intake}\ (kg) = \Sigma\ OM_{intake\text{-}1}\ (kg) + OM_{intake\text{-}2}\ (kg) + \ldots\ldots + OM_{intake\text{-}i}\ (kg)\ (i = 1\ldots\ n)$$

The digestible organic matter intake of each feed material i is calculated as:

$$DOM_{intake\text{-}i}\ (kg) = OM_{intake\text{-}i} \times DCOM_{\ \text{-}i}\ /\ 100$$

The total net digestible organic matter intake (tot-DOM$_{intake}$ in kg) , of the total ration with n feed ingredients, is calculated as the sum of the digestible organic matter intakes of the individual feed ingredients:

$$\text{The tot- }DOM_{intake}\ (kg) = \Sigma\ DOM_{intake\text{-}1}\ (kg) + DOM_{intake\text{-}2}\ (kg) + \ldots\ldots + DOM_{intake\text{-}i}\ (kg)\ (i = 1\ldots\ n)$$

Total VS excretion 'under the tail'
VS excretion " under the tail " (VS-excr) is calculated as:

$$VS\text{-}excr = tot\text{-}OM_{\ intake}\ (kg) - tot\text{-}DOM_{\ intake}\ (kg) + VS_{\ urine}\ (kg)$$

VS from feed losses
In practice feed losses occur, ie not all feed is ingested by the animal, feed is also 'messed'. It is assumed that all feed losses end up in the solid manure. The contribution of feed losses to the VS in manure (VS $_{feed\ loss}$) are calculated as:

The net organic matter intake of each feed ingredient i, including feed loss (OM-IFL $_{intake\text{-}i}$) is calculated as:

$$OM\text{-}IFL_{\ intake\text{-}i}\ (kg) = DM\text{-}IFL_{\ intake\text{-}i}\ (kg) \times (1000\text{-}CA_{\ i}\ (g\ /\ kg\ DM))$$

The total net organic matter intake including feed loss (tot-OM-IFL $_{intake}$ in kg), of the total ration with n feed ingredients, is calculated as the sum of the organic matter intake of the individual feed ingredients:

$$\text{The tot-}OM\text{-}IFL_{\ intake}\ (kg) = \Sigma\ OM\text{-}IFL_{\ intake\text{-}1}\ (kg) + OM\text{-}IFL_{\ intake\text{-}2}\ (kg) + \ldots\ldots + OM\text{-}IFL_{\ intake\text{-}i}\ (kg)\ (i = 1\ldots\ n)$$

The VS that is attributed to the manure via feed loss is calculated as:

$$VS_{\ feed\ loss} = tot\text{-}\ OM\text{-}IFL_{\ intake}\ (kg) - tot\text{-}OM_{\ intake}\ (kg).$$

VS from litter
Straw as litter ends up in solid manure, whereas sawdust and lime end up in slurry. Lime is assumed to contain 0% of organic matter and for other litter, 90% of the dry matter is assumed to be organic matter.

$$VS_{\ litter} = 0\% * kg\ DM\ lime + 0.9 * kg\ DM\ other\ litter$$

Total VS excretion
Total VS excretion including feed loss (VS excrincl) is calculated as:

$$\text{VS-excrincl} = \text{VS-excr} + \text{VS}_{\text{feed loss}} + \text{VS}_{\text{litter}}$$

The above method for calculating the VS in manure is used for dairy cows and associated young stock. The following method was used for the other ruminants.

$VS = \sum(Nexretie_T * \text{Factor})$, where:

Nexcretion $_{(T)}$: total N excretion per animal category in kg per day (dairy cattle, young stock and (total) other ruminants). This N-excretion is derived from BEX (section 2.1), but not reduced by the gaseous N-losses from stable and storage.

Factor : conversion factor from N to VS (OM / N ratio in manure, Table 2.5.2)

Table 2.5.2 *Parameter values for determining the methane emission factors of manure management systems. For explanation of the parameters, see text above.*

Animal category	B_0	OM/ N factor *		MCF		
		Liquid manure	Solid manure	Liquid manure	Solid manure	Pasture manure
Dairy cows	0.22			17 or 3 **	2.0	1
Young stock	0.22			17 or 3 **	2.0	1
Other ruminants ***	0.20	15.6	25.8		1	

Source: Lagerwerf et al., 2019.

* OS / N is only used for VS calculation of other ruminants

** undigested vs. digested

*** IPCC distinguishes several animal categories, which differ in parameter B_0 (eg goats 0.18; sheep 0.19; horses 0.3). In ANCA these have been provisionally placed under one category with a B_0 value of 0.2.

2.5.6.2.3 Manure digestion

In ANCA you can specify how much slurry is anaerobically digested externally and / or on the farm. In ANCA we assume that this manure has been in storage for less than 30 days before it goes into the digester, so for this amount of manure an MCF (see Table 2.5.2) is used of 3 instead of 17. Methane production during the anaerobic digestion has been assumed to be 95% of the maximum methane production (B_0), of which 4.3% (Hjort-Gregersen, 2014) escapes through leakage.

2.5.6.3 CO_2 emissions from feed production and feed consumption

2.5.6.3.1 Which items are included?

For the cultivation of crops, all emissions associated with the production and use of the inputs and auxiliary materials must be included. For synthetic fertilizers, this concerns both energy consumption and nitrous oxide emission during production, as well as nitrous oxide emission during application. Lime fertilizers and pesticides are also included in the inputs. Emissions must also include the use, production and maintenance of machines. This concerns fuel consumption on the farm itself and energy and raw materials for production and maintenance.

Crop processing involves the use of energy and auxiliary materials. If more products are created, the emission is allocated to the various co-products based on economic allocation. ANCA does not yet take this allocation based on economic value into account in the case of arable crops. For the time being, the allocation of emissions to, for example, straw and grain in cereals is based on weigth (kilogram).

For compound feed production emissions from all steps prior to the arrival of raw materials in the factory are included. Emissions related to the energy required for grinding, mixing and pelletizing are added to this.

Transport takes place between all steps of cultivation, processing, compound feed production, and farm. All emissions associated with transport are also included.

Many different types of feed are used in dairy farming.

- First, there is the roughage that is grown on the farm. This may concern grass, maize silage, but also other crops, such as grains or field beans. Grass and alfalfa are harvested several times a year. The other crops are harvested once per season.
- Purchased roughage
- Purchased by-products from industry
- Purchased compound feed.

Since the calculation of the greenhouse gas emissions is a chain approach, emissions of all groups must be calculated. The PEFCR Feed provides an overarching schedule of all emission calculations.

2.5.6.3.2 Cultivation of own feed

For the production of own roughage, farm-specific data is used about inputs, which are requested in ANCA. This concerns the production and application of animal manure and synthetic fertilizer. Nitrous oxide emissions are described in sections 2.3.2.2 (soil) and 2.3.2.3 (manure). The emissions associated with synthetic fertilizer production are derived from Agrifootprint. The machine usage for growing crops is standardized. Section 2.5.6.7 provides a detailed description of this.

2.5.6.3.3 Purchased feed

As ANCA primarily focuses on the utilization and losses of N, P and C within the boundaries of the farm, the CO_2 emissions resulting from the production of feed (fertilizers, field work, transport, storage and processing) would not be included when this feed is not grown on the farm but elsewhere. These indirect emissions from purchased feed ingredients are calculated using standard values for emissions per kg of product taken from FeedPrint / Agrifootprint (FeedPrint, 2018) (see also Appendix 1). The CO_2 emissions in Appendix 1 include land use change and transport up to the supplier. Emissions from transport to the farm are included separately.

If feed is sold from the initial stock, the corresponding CO_2 is deducted from the purchased quantity (= net purchase).

Feed sold in the reference year itself is already included in feed production (separation of processes).

Emissions related to feeding products are calculated separately, depending on the type of product.

2.5.6.4 Application of fertilizers (lime and urea)

There are a number of C-containing products that are used in the cultivation of crops. This concerns (Source: IPCC Guidelines (2006); Fifth Assessment Report, 2014):

Urea: kg Nureum * NURE_URE * EF_CO_2_Nure / 1000 * 44/12, where

NURE_URE = 60/28: (Urea = CH_4N_2O, so 60/28)
EF_CO_2_Nure = 200 (g CO_2 / kg urea)

Lime: (kgKalk_Dolo * EF_CO_2_Dolo / 1000 + kgKalk_Lime * EF_CO_2_Lime / 1000) * 44/12, where

EF_CO_2_Dolo = 120 (g CO_2 / kg dolomite)

EF_CO_2 _Lime = 130 (g CO_2 / kg limestone)

For the time being, ANCA assumes that 90 kg / ha of pure lime is applied, which consists of 64% Dolomite lime. From 2019, amount and composition will be derived from data entries in ANCA.

Appendix 2 provides an overview of all emission coefficients of carbon dioxide (directly and indirectly) by using different products and processes in the management of the dairy farm.

2.5.6.5 Imported fertilizers

Synthetic fertilizer use must be multiplied by the EF value of the different types of synthetic fertilizer according to Table 2.5.3.

Table 2.5.3 *Emission of CO_2 in the production of various synthetic fertilizers, emission factor (EF) in g CO_2 -eq / kg, excluding emissions for transport to the farm.*

fertilizer type	emission coefficient	Unit	Source
ammonium	3099	g CO_2-eq / kg pure N	Feedprint, 2018
Nitrate	3625	g CO_2-eq / kg pure N	Feedprint, 2018
Urea	1332	g CO_2-eq / kg pure N	Feedprint, 2018
nitrogen combinations	6685	g CO_2-eq / kg pure N	Feedprint, 2018
Phosphate	1218	g CO_2-eq / kg pure P_2O_5	Feedprint, 2018
Potassium	563	g CO_2-eq / kg pure K_2O	Feedprint, 2018
lime, limestone	32	g CO_2-eq / kg limestone	Feedprint, 2018
lime, dolomite	44	g CO_2-eq / kg dolomite	Feedprint, 2018

For organic manure only transport emissions are taken into account .

2.5.6.6 Use of pesticides

The use of pesticides in kg active substance (AS) is included as standard in accordance with Table 2.5.4.

Table 2.5.4 *Standard consumption of plant protection products (kg AS / ha), source: www.agrimatie.nl.*

Kind	land use	use
Nematicide	Grassland	0.02
Nematicide	arable land	0
Herbicide	Grassland	0.16
Herbicide	arable land	1.15
Fungicide	Grassland	0
Fungicide	arable land	0.01
Others	Grassland	0
Others	arable land	0.01

The use of pesticides must be multiplied by the EF value of the various pesticides, as indicated in Table 2.5.5 .

Table 2.5.5 *Emission of CO_2 from the production of various pesticides, emission factor (EF) in g CO_2 -eq / kg AS.*

crop protection agent	emission coefficient	Unit	Source
nematicide	10183	g CO_2-eq / kg as	Ecoinvent, 2018
herbicide	11541	g CO_2-eq / kg as	Ecoinvent, 2018
fungicide	5791	g CO_2-eq / kg as	Ecoinvent, 2018
Others	9867	g CO_2-eq / kg as	Feedprint, 2018

The above emissions do not include transport to the farm.

2.5.6.7 Machine use in the cultivation of crops

2.5.6.7.1 Introduction

The energy consumption for production and maintenance is based on Ecoinvent (Nemecek & Kägi, 2007). Below is an overview of all operations for the different products.

2.5.6.7.2 Grassland activities

The number and frequency of actions differs per type of grassland use. Therefore, a distinction is made between:

- 1 cut grazing
- 1 cut fresh grass (summer stall feeding)
- 1 cut grass silage
- 1 cut hay
- 1 cut grass drying

Table 2.5.6 shows which activities occur per type of grassland and how often they occur.

Table 2.5.6 *Frequency of activities per cut grassland for grazing, summer stall feeding, harvesting for grass silage, harvesting for hay and harvesting for grass drying (FeedPrint, 2018).*

	Cut grazing	Cut fresh grass (summer stall feeding)	Cut grass silage	Cut hay	Cut grass drying
Synthetic fertilizer	1	1	1	1	1
Pasture topping	0.5				
Mowing		1	1	1	1
grass loading		1	1		1
Teddering			2	3	
Windrowing			1	1	
Packing silage			1		
large square baler				1	

The following tables indicate which general activities (Table 2.5.7) and which sow-related activities (Table 2.5.8) occur in grassland.

Table 2.5.7 *Frequency of general activities per hectare of grassland.*

	grassland, field work
liming	0.25
harrowing	0.5
Rolling	0.5

Table 2.5.8 *Frequency of activities per hectare of grassland for reseeding, overseeding or for rotational cropping with an arable crop.*

	reseed per ha	overseed per hectare	Rotational cropping per hectare
spraying	1	1	
control weeds	1	1	
plowing	1		1
harrow	2		2
sow	1		1

Some activities are expressed per cut. Because the number of cuts is not requested in ANCA, that number must be estimated based on the annual yield. This is done by assuming a certain cutting yield. The principles used are:

Gross cut weight fresh grass = 1500 kg DM / ha
Gross cut weight of summer stall fed grass = 1800 kg DM / ha
Gross cut weight grass silage, hay and drying = 3000 kg DM / ha

The total emissions from the use of the machine are then calculated as the sum of:

- the products of the numbers of cuts and the emissions from machine use per cut per individual type of land use,
- the products of the number of hectares and the frequencies per hectare for lime spreading, rolling and harrowing,
- the emissions for (re-) sowing and overseeding. The number of hectares that have been sown or re-sown (re-sowing grass after grass and sowing grass after arable land) is multiplied by the relevant emissions.

Table 2.5.9 *Energy consumption per unit of grassland activity, for the types of diesel, electricity, gas, kerosene and coal.*

Activity	unit	diesel, direct (kg)	Electric, indirect (MJ)	Gas, Indirect (MJ)	Kerosene (indirect (MJ)	Coal, indirect (MJ)
Plowing	Ha	23.0916	12.4589	8.2835	13.3528	1.4143
Harrowing	Ha	9,408	9.7013	6.0594	11.8508	1.0345
Sowing	Ha	4,326	7.4309	5.0199	7.6687	0.8571
Apply slurry	m3	0.6615	0.4067	0.3681	0.0724	0.0628
Apply solid manure	tons	1,2852	3,217	2.8543	0.7859	0.4873
Apply synthetic fertilizer	Ha	2,4024	1.0654	0.7576	0.9585	0.1293
Liming	Ha	2,4024	1.0654	0.7576	0.9585	0.1293
Spraying	Ha	2.4864	2.7944	1.8454	3.0413	0.3151
Weed control	Ha	2.4864	2.7944	1.8454	3.0413	0.3151
Pasture topping	Ha	4.2	1.3244	0.9282	1.2421	0.1585
Mowing	Ha	4,788	2.3555	1,6605	2.1723	0.2835
robotic harvester	Ha	25.62	131.6678	88.56	137.3242	15.12
Teddering	Ha	3,192	0.9888	0.6913	0.9314	0.118
Windrowing	Ha	2.94	4.0348	2.5969	4,643	0.4434
Loading	Ha	5,292	6.9664	5.3727	4,7093	0.9173
Small square bales	Ha	5,712	34.7868	27.5024	21.0089	4.6955
Large square bales	Ha	11,256	26.7177	17.1467	30.9298	2.9275
Packing silage	Ha	2.52	1.4664	1.0937	1.1299	0.1867
Rolling	Ha	4.2	2.8704	1.8982	3.1144	0.3241
Grass chain harrowing	Ha	4.2	2.8704	1.8982	3.1144	0.3241

2.5.6.7.3 Arable land activities

For all arable crops, activities have been distinguished, which basically boil down to preparing the land (plowing, seedbed preparation, sowing, crop management (fertilizers, pest and disease control), harvesting and post-harvest activities. For these crops the total emissions are given , as calculated by FeedPrint / Agrifootprint. The emissions per kg of product are then calculated by dividing the emissions of all inputs and the machine usage by the yield generated on the farm.

Table 2.5.10 *Energy consumption per hectare of arable crop in ANCA, of the types of diesel, electricity, gas, kerosene and coal.*

Crop	diesel, direct (kg)	Electricity, direct (kWh)	Electricity, indirect (MJ)	Gas, indirect (MJ)	Kerosene, indirect (MJ)	Coal, indirect (MJ)
Green corn	95.85	0	124,188	82,366	133,849	14,062
WPS grains	95.85	0	124,188	82,366	133,849	14,062
Lucerne	128.05	0	187.006	124,939	198,172	21,331
Red clover	128.03	0	186,993	124.93	198,157	21.33
Beets	192.86	0.2681	524.78	338.8	600,037	57,844
Maize (CCM, WECS)	123.79	1.0247	197,388	130,138	215,634	22,219
Grains, coarse grain	114.77	0	176,938	116,669	193,245	19,919
Grains, small grain	112.15	0	155,709	102,815	169,526	17,554
Grass seed	114.77	0	176,938	116,669	193,245	19,919
Legumes	86.19	0	118,342	78,515	127,454	13,405
Potatoes	196.04	1.7771	410,799	268.39	457,892	45.823
Seed potatoes	196.04	1.7771	410,799	268.39	457,892	45.823
Onions and bulbs	196.04	1.7771	410,799	268.39	457,892	45.823
Vegetables, leaf	128.05	0	187.006	124,939	198,172	21,331
Vegetables, non-leaf	128.05	0	187.006	124,939	198,172	21,331
Other arable farming	128.05	0	187.006	124,939	198,172	21,331

2.5.6.7.4 Converting grass and arable land activities into CO_2

To calculate the CO_2 , the total quantities of diesel and electricity must be multiplied by an EF value. These EF values are listed in Table 2.5.11. Prior to this the use of diesel in kilograms is converted to MJ's per kg (43.2 MJ / kg) and electricity in kWh is converted to MJ's per kWh (3,6 MJ / kWh).

Table 2.5.11 *Coefficients of emission (g CO_2 -eq per MJ) for various energy carriers, excluding transport to the farm.*

Energy carrier	EF combustion (g CO_2-eq per MJ)	EF production (g CO_2-eq per MJ)	EF indirect (g CO_2-eq per MJ)
Electricity (gray)	-	200.4	
Electricity (green)	-	13.3	
Diesel	72.5	12.3	
Normal gas	56.6	19.9	
Biogas	0	24.5	
Propane	66.7	18.6	
Fuel oil	77.4	11.5	
Electricity, indirectly			200.4
Gas, indirectly			68.3
Kerosene, indirect			92.8
Coal, indirectly			134.6

CO_2 direct = kg diesel * MJ_per kg Diesel * (EF_Diesel combustion + EF_Diesel production) +
kWh elek * MJ_per kWh Elec * EF_ElectricityDirect

EF_ElectricityDirect = see Table 2.5.16

CO_2 indirect = MJ electricity * EF_Electricity indirect +
MJ natural gas * EF_Natural gas +
MJ kerosene * EF_Kerosine +
MJ brown coal * EF_Kolenl

2.5.6.7.5 Artificial feed drying

If feed is dried artificially, this energy must be included in the CO_2 emission. ANCA now distinguishes artificially dried grass pellets and grass bales (dried from 200 g / DM to 920 g / DM), maize silage (dried from 310 g / DM to 910 g / DM), lucerne and clover (dried from 300 g / DM to 910 g / DM).

CO_2 emissions are taken into account for drying and baling or pelleting according to Table 2.5.12.

Table 2.5.12 *Emission of CO_2 during the drying of various products, emission factor (EF) in g CO_2-eq / tonne of incoming product, excluding transport to the drying location and back to the farm.*

Drying of	emission coefficient	Unit	Source
Grass bale	404	kg CO_2-eq / ton input	Feedprint, 2018
Grass pellet	470	kg CO_2-eq / ton input	Feedprint, 2018
Maize silage	366	kg CO_2-eq / ton input	Feedprint, 2018
other roughage	332	kg CO_2-eq / ton input	Feedprint, 2018

2.5.6.7.6 Machine use when feeding

When all products are on the farm, they must still be fed. Energy consumption is calculated for all feed ingredients, except compound feed, which in turn includes emissions for direct fuel consumption and for production and maintenance. Table 2.5.13 shows the energy consumption per ton of product fed. Feeding compound feed takes so little energy that no separate energy consumption is calculated for it.

Table 2.5.13 *Energy consumption of feeding, per ton of product of the various feed ingredients, and the types of diesel, electricity, gas, kerosene and coal. The products belonging to the different feed ingredients are listed in Appendix 1.*

	diesel, direct (kg)	Electricity, indirect (MJ)	Gas, indirect (MJ)	Kerosene, indirect (MJ)	Coal, indirect (MJ)
Roughage [1] (tons of product)	2.5377	2.0496	1.3976	2.0665	0.2386
other roughage [1] (tons of product)	3.9206	4.2212	2.8162	4,488	0.4808
by-products [1] (tons of product)	2.3789	8.2959	5,222	9.9837	0.8916
fresh grass [1] (tons of product)	0.3514	0.2626	0.1816	0.2553	0.031

[1] The products belonging to the different feed materials are listed in Appendix 1.

Please refer to Table 2.5.11 for the conversion of this energy consumption to CO_2 .

2.5.6.8 Other energy

2.5.6.8.1 Introduction

Energy is also consumed in other ways to produce milk, meat and crops. ANCA also maps out the magnitude of the associated CO_2 losses. To this end, ANCA takes into account:

- Consumption of electricity for milking, cooling and lighting,
- Consumption of gas for hot water and heating in general,

- Consumption of propane for heating in general and water, and
- Fuel oil consumption for heating water and general consumption.

2.5.6.8.2 Consumption of electricity, gas, propane, fuel oil

The following calculation rules (KWIN, 2018/2019) are used in the standard calculation:

Cooling milk (electricity): Depending on pre-cooler and heat recovery installation (y/n).

No pre-cooler and no heat recovery: consumption = 13.0 * milk supply / 1000 (KWh)
No pre-cooler, heat recovery: consumption = 14.0 * milk supply / 1000 (KWh)
Pre-cooler and no heat recovery: consumption = 8.0 * milk supply / 1000 (KWh)
Pre-cooler and heat recovery: consumption = 10.0 * milk supply / 1000 (KWh)

Milking (electricity):

No milking robot: Consumption = 500 * number of milking clusters (KWh)
Milking robot single box: Consumption = 10950 * number of AMS systems (KWh)
Milking robot multibox: Consumption = 21900 * number of AMS systems (KWh)

Other, including lighting (electricity):

Consumption = 1924 + 16.3 * number of cows (KWh)

Heating water (electricity, gas, propane or fuel oil):
First calculate hot water consumption in liters per day:

Milking robot single box and hot cleaning: hot water = 220 liters
Milking robot single box and circulation cleaning: hot water = 228 liters
Milking robot multibox and hot cleaning: hot water = 325 liters
Milking robot multibox and circulation cleaning: hot water = 220 liters

Traditional milking parlor:
a: (20 + number of milking clusters * 5) * 0.8
b: (20 + number of milking clusters * 5) * number of milking times
c: (a + b) * 0.40 if generously dimensioned
d: (number of cows * 1.0) * if no heat recovery installation
e: (45 + number of cows * 0.75) / 2

Hot water = a + b + c + d + e

No heat recovery:

Heat source is electric: Consumption of electricity = hot water * 29.9644 (KWh)
Heat source is gas: Consumption gas = hot water * 5.7631 (m^3)
Heat source is propane: Consumption of propane = hot water * 7.3002 (ltr)
Heat source is heating oil: Consumption heating oil = hot water * 5.0925 (ltr)

Heat recovery:

Heat source is electric: Consumption of electricity = hot water * 12.7348 (KWh)
Heat source is gas: Consumption gas = hot water * 3.6019 (m^3)

Heat source is propane: Consumption of propane = hot water * 4.5627 (ltr)
Heat source is heating oil: Consumption heating oil = hot water * 3.1828 (ltr)

Other ruminants (electricity and gas):

For other ruminants, standard consumption is used, see Table 2.5.14

Table 2.5.14 *Standard consumption of electricity and gas for other ruminants (Anonymous, 2018).*

	electricity (kWh / yr)	gas (m^3 / yr)
Breeding bulls,> 1 year (cat. 104)	25	0
Pasture and suckler cows (cat. 120)	8.3	0
Nursing calves, rosé or red meat (cat. 115)	20	8
Rosé calves, 3 months - slaughter (cat. 116)	11.5	0
Rosé calves, 2 weeks - slaughter (cat. 117)	14.6	2.9
Red meat bulls, 3 months - slaughter (cat. 122)	25	0
Breeding sheep, incl. Lambs (cat. 550)	5.3	0
Meat sheep, <4 months (cat. 551)	5.3	0
Other sheep,> 4 months (cat. 552)	5.3	0
Milk goats (cat. 600)	8.3	0
Rearing and meat goats, <4 months (cat. 601)	8.3	0
Rearing and meat goats,> 4 months (cat. 602)	8.3	0
Ponies (cat. 941)	0	0
Horses (cat. 943)	0	0

2.5.6.9 Own electricity production

On-farm production of energy also generates CO_2 . The average EF depends on the form of generation. See Table 2.5.15, below.

Table 2.5.15 *Emission of CO_2 in the production of energy, emission factor (EF) in the g CO_2 -eq / MJ.*

Energy production via	emission coefficient	unit	Source
biomass	12.78	g CO_2-eq / MJ	Simapro, 2018
Wind	3.79	g CO_2-eq / MJ	Simapro, 2018
Sun	22.77	g CO_2-eq / MJ	Simapro, 2018

At data entry, one ‘other’ form of energy generation can be specified, so that the average EF per MJ becomes equal to:

The average EF per MJ becomes:

EFelek_prod = fraction Bio * 12.78 + fraction Wind * 3.79 + fraction Sun * 22.77 + fraction Other * emission coefficient ‘other’, where

emission coefficient 'other' = weighted average of the well-known renewable sources:

(fraction Bio * 12.78 + fraction Wind * 3.79 + fraction Sun * 22.77) /
(fraction BIO + fraction WIND + fraction SUN)

If own energy is produced and possibly supplied back to the electricity grid, the energy supply must first be calculated:

OwnElek = production of electricity - supply of electricity to grid
Supply = Electricity consumption - OwnElek

To calculate the CO_2 per energy carrier, the energy quantities must be multiplied by the EF values. In Table 2.5.11 shows the EF values per fuel.

The above emissions do not include transport to the farm.

CO_2 electricity: Supply in kWh * 3.6 * (EFelek_grey * share of gray electricity + _
EFelek_green * share of green electricity)
+ OwnElek in kWh * 3.6 * (EFelek_prod * (1 - PcGVO / 100) + _
EFelek_grey * PcGVO / 100
CO_2 gas: Consumption of gas in m3 * proportion of normal gas * 31.65 * EFgas_norm
+ Consumption of gas in m3 * share of biogas * 21.80 * EFgas_bio

CO_2 prop: Consumption of propane in ltr * 0.51 * 45.2 * EF propane
CO_2 oil: Fuel oil consumption in ltr * 0.84 * 41.0 * EF fuel oil

2.5.6.10 Other input items

2.5.6.10.1 Litter
The use of litter must be multiplied by the EF value of the different litter types according to Table 2.5.16.

Table 2.5.16 *Emission of CO_2 in the production of different types of litter, emission factor (EF) in g CO_2-eq / kg, excluding transport to the farm.*

litter type	emission coefficient	unit	Source
straw	245	g CO_2-eq / kg	Feedprint, 2018
sawdust	22	g CO_2-eq / kg	Agri footprint, 2018
lime	32	g CO_2-eq / kg	Agri footprint, 2018
Other	100	g CO_2-eq / kg	Agri footprint, 2018

2.5.6.10.2 Water supply
ANCA assumes 0.411 g CO_2-eq per liter and with 1.749 m^3 water per tonne of milk.

2.5.6.10.3 Livestock supply
Calculations in ANCA use a net input/output of livestock in kg. For each animal group (cows, heifers, calves), the net input (= input - output) is first calculated, with a maximum of 0 kg. A quantity of CO_2 is subsequently calculated per kg animal in accordance with Table 2.5.17.

Table 2.5.17 *Emissions of CO_2 in the purchasing and culling of different age groups of cattle, emission factor (EF), in grams, of CO_2 eq / kg.*

Animal group	emission coefficient	unit	Source
Cows	10,629	kg CO_2-eq / kg live weight	Agri footprint, 2018
Heifers	10,629	kg CO_2-eq / kg live weight	Agri footprint, 2018
Calves	10,667	kg CO_2-eq / kg live weight	Agri footprint, 2018
nursing calf	10,667	kg CO_2-eq / kg live weight	Agri footprint, 2018

The above emissions do not include transport to the farm.

2.5.6.10.4 Supply of covering material
The use of covering material is calculated from the amount of the grass products and maize silage products per tonne DM according to Table 2.5.18.

Table 2.5.18 *Use of plastic as a covering material for grass silage and maize silage (kg / ton DM), source: Hospers et al., 2019.*

Roughage type	Use
Grass silage	0.95
Corn silage	1.49

The use of covering material must be multiplied by the EF value of covering material. The EF value of plastic is 3,053 kg of CO_2 equivalents per kg of plastic, excluding transport to the farm.

2.5.6.11 Transport

The footprint of purchased feed already takes into account transport from the producer / processor / compound feed factory to the farm. No additional transport emissions are calculated for this. All other products have a footprint calculated to a regional delivery point, i.e. a trader in fuels or fertilizers, etc. All these products still have to be transported by truck to the primary farm. In the calculations, ANCA assumes that no other forms of transport are used than trucks. Standard distances from regional delivery point to farm are used for all these products (Table 2.5.19). The CO_2 emissions associated with this transport are estimated at 101 g CO_2 per ton per km.

Table 2.5.19 *Fixed transport distances (km) for various products.*

Product	Standard distance
Fresh grass, grass products and maize silage products	50
Other roughage and wet by-products	100
Concentrate feeds and milk products	100
Cover materials	50
Diesel	300
Drying	100
Gas	100
Pesticides	50
Synthetic fertilizer	100
Oil	100
Organic manure	100
Straw	50
Cattle	250

2.5.6.12 Organic matter balance

Crop residues and organic manure are the main products supplying organic matter (OM) to the soil. ANCA calculates the OM supply via crop residues from grass and maize (WPCS, WECS, CCM) by closely matching items that are also used in the BEN module. With regard to the supply via crop residues from other crops, crop-specific effective organic matter contributions from the literature have been used.

For grass and maize (excluding any residual plant in case of WECS and CCM), BEN assumes a crop residue (stubble and root) of 75 and 15 kg N per ha, respectively. In an equilibrium situation (continuous cropping), it is assumed that the same quantity is broken down every year. When both crops are rotated, it is assumed that an additional 75 kg N per ha will be sequestered annually under new grassland, with a maximum of 300 kg N per ha, but this amount will be completely broken down in the following arable period, regardless of its duration. Just like BEN, BEC does not yet make a visible distinction between the organic matter balances of the grassland and the arable land. To calculate the organic matter contributions of the roots and stubble of grass and maize, ANCA converts the N content into effective organic matter. To calculate the effective organic matter, the supplied organic matter must be corrected for the part that has already been exhaled during the first 12 months; the organic matter that remains after that period is called effective organic matter. Table 2.5.20 shows the conversion factors ('HC values') used in ANCA.

Table 2.5.20 *Humification coefficients ('HC values') of fresh plant material, crop residues and organic fertilizers, the amount of organic matter per kg N-total in manure, and the fixed contribution effective organic matter contribution of various fertilizers (http://www.kennisakker.nl/kenniscentrum/handleidingen/adviesasis-voor-de-bemesting-van-akkerbouwgebladen-organische-stof).*

Source	HC [1]	OM / N	E.O.M. [1] Contribution	
	(kg OM per kg OM supplied)		(per m^3) [2]	(per kg N-total [2])
Fresh plant material [3]	0.25			
Crop residues [4]	0.30			
Ruminants slurry, manure code 14	0.70	17.8 [5]	50	12
Ruminants solid manure, manure code 10	0.70	20.1 [5]	98	14
Pasture manure ruminants [6]	0.70	17.8 [5]	50	12
Non-ruminants slurry, manure code 50	0.33	11.3 [5]	27	4
Ruminants solid manure, manure code 39	0.70	12.3 [5]	84	4
Compost [7]	0.90	30.1 [5]	152	27
Ruminants liquid fraction, manure code 11	0.70	11.7 [5]	29	8
Ruminants solid fraction, manure code 13	0.70	24.1 [5]	118	17
Fertilizer substitutes (blowdown lye, mineral concentrate)	0.33	2.9 [8]	7	1
Digestate [9]	0.90 [10]	6.0 [5]	30	5
Other [6]	0.70	17.8 [5]	50	12

[1] HC: the humification coefficient is the fraction that is still effectively present one year after application: 'EOM'

[2] Based on Table 1.2.

[3] Grazing, cutting and harvesting losses, feed leftovers.

[4] Roots, stubble, grass sod, WPCS, WECS and CCM.

[5] Den Boer *et al.* , 2012.

[6] Same as ruminants slurry.

[7] Average biodegradable waste and green compost.

[8] Velthof, 2011.

[9] Average of cattle and fattening pigs and degradation of Norg of 25-50%.

[10] Same as compost, due to prior mineralization.

The input items for the (effective) organic balance are shown in Table 2.5.20. The organic matter balance is initially calculated separately for the grassland ('input and output per hectare of grassland') and for the arable land ('input and output per hectare of arable land, where arable land consists of arable roughage crops (WPCS, WECS, CCM, alfalfa, field bean), and marketable crops (maize grain, cereals, root crops, etc.). Also for the organic material balance, only in the second step the weighted average of the individual types of land use is calculated. Hence in the amounts 'per hectare' is it is therefore not initially about outcomes per hectare of land, but about outcomes per hectare of a certain type of land use (grassland, arable land).

The item OMIn1 (effective organic matter from pasture manure) applies to grassland only, as follows:

$EOMIn1 = In1 \times OM / N_{manure} \times HC_{manure}$, where:

OM / N_{manure} and HC_{manure} : see Table 2.5.20 for manure from grazing animals

The item OMIn2 (effective organic matter from 'stable manure') cannot simply be derived from the crop and rotation-specific items from the BEN calculation if In2 consists of, among other things, manure from grazing animals. Because in that case manure (In2) is defined as the sum of excreted manure and urine including feed leftovers-N. Because OM / N_{manure} is not the same as $OM / N_{feed\ leftovers}$ and HC_{manure} is not the same as $HC_{fresh\ crop}$, the contribution of the separate two components must first be calculated. To this end, the weighted average N content of the dry matter (DM) in the ensiled roughage is calculated based on the input data from BEX (N% roughage,% N in DM). Assuming that 90% of the feed DM consists of organic matter, the following applies:

> $OM / N_{feed\ leftover}$ = (kg OM per kg DM) / (kg N per kg DM) = (90/100) / (weighted N content in kg per kg of roughage, by-products and concentrates)

The effective organic matter that is supplied as 'stable manure' (OMIn2) on grassland and arable land, with a distinction between continuous and rotational cropping, is equal to:

> $EOMIn2_{pure\_manure}$ on grassland = Fraction 'real' manure x In2 on grassland x OM / N_{manure} x HC_{manure}

> $EOMIn2_{pure\_ manure}$ on arable land = Fraction 'real' manure x In2 on arable land x OM / N_{manure} x HC_{manure}

> with fraction 'real' manure = ((In2 at average farm level, kg N / ha - weighted average feed leftover of all feed materials used, kg N / ha) / (In2 at average farm level, kg N / ha))

In2 at average farm level is the sum of total N supply (kg N / ha) from manure from ruminants and non-ruminants, and compost. OM / N_{manure} and HC_{manure} are based on the N-supply weighted average values of the three types of manure used (Table 2.5.21). It is assumed that there is no difference in the supply of effective organic matter between unfermented and fermented manure. With fermented manure the OM / N ratio (becomes lower) and the HC (becomes higher) changes in such a way that the supply of EOM is equal to that of unfermented manure.

The effective organic matter applied via feed leftovers on the land ($OMIn2_{feed\ leftover}$) is equal to:

> $EOMIn2_{feed\ leftover}$ on grassland = (1 – Fraction 'real' manure) x In2 grassland x $OM/N_{feed\ leftover}$ x $HC_{fresh\ crop}$

> $EOMIn2_{feed\ leftover}$ on arable land = (1 - Fraction 'real' manure) x In2 Arable x $OM/N_{feed\ leftover}$ x $HC_{fresh\ crop}$

> $HC_{fresh\ crop}$ = 0.25 and $OM / N_{feed\ leftover}$ based on the average N content of the ensiled roughage

The organic matter contributions from grazing-, cutting and harvesting losses are based on the same HC's as those for fresh crops. This is a simplification of reality because the different crops will actually differ in degradability.

The effective organic matter that ends up on the grassland as grazing and cutting losses ($EOMIn6_{grass}$) is equal to:

> $EOMIn6_{grassland}$ = ($In6_{grassland}$) x $OM / N_{cultivation\ grass}$ x $HC_{fresh\ crop}$

where

$In6_{grassland}$ = 5% to 20% of the N yield (kg N / ha) of the grassland (depending on the grassland use, see Table 1.1), $OM / N_{cultivation\ grass}$ = (kg OM / kg DM) / (kg N / kg DM in home-grown grass) = (90/100) / (kg N / kg DM in home-grown grass), and $HC_{fresh\ crop}$ = 0.25.

The effective organic matter that ends up on the arable land through harvesting losses is limited to that on maize land ($EOM_{maizelandharvestloss}$) because it is assumed that no other crop losses occur for the other arable forage crops and marketable arable crops, at least not in addition to the EOM contribution that are already attributed to these crops (see later in this section).

$EOM_{maizelandharvestloss}$ (kg per ha of cultivated land) = SO / BO x ($In6_{maize\ land}$) x OM / $N_{cultivation\ of\ maize}$ x $HC_{fresh\ crop}$

Where

SO = maize land area, BO = arable land area, $In6_{maize\ land}$ = 2% (Table 1.1) of the N yield (kg N / ha) of maize (WPCS, WECS and CCM) from own land, OM / $N_{cultivation\ maize}$ = (kg OM / kg DM) / (kg N / kg DM in home-grown maize) = (90/100) / (kg N / kg DM in home-grown maize) and $HC_{fresh\ crop}$ = 0.25.

With regard to organic matter contributions from the crop residues, a slightly lower HC than the HC of fresh crops is assumed (Table 2.5.20), but OM / N ratios that are assumed to be the same as those of the fresh crop. This is a simplification of reality because the crop residues will actually have a different N content (protein content). The effective organic matter that ends up on the grassland as crop residue ($EOMIn7_{grassland}$) is equal to:

$EOMIn7_{grassland}$ = ($In7_{grassland}$) x OM / $N_{cultivation\ grass}$ x $HC_{crop\ residue}$

Where $In7_{grassland}$ = 75, OS / $N_{cultivation\ grass}$ = kg OM per kg grass-N, and $HC_{crop\ residue}$ = 0.30.

The effective organic matter that ends up on the arable land via crop residues ($EOS_{cropresiduearableland}$) is equal to

$EOS_{cropresiduearableland}$ = ((SO x ($In7_{maize\ land}$) x OM / $N_{cultivation\ maize}$ x $HC_{crop\ residue}$) + ((BO-SO) x $EOS_{crop\ residue\_not\_maïsland}$)) / BO

Where SO = maize land area, $In7_{maize\ land}$ = 15, OM / $N_{cultivated\ maize}$ = kg OM per kg maize-N, $HC_{crop\ residual}$ = 0.30, BO = arable land area, and $EOS_{crop\ residue\_not\_maïsland}$ = the area-weighted EOM contributions of the non-maize arable crops and their by-products left behind (if any) (Table 2.5.22).

The contribution of effective organic matter in the form of grazing and cutting losses on grassland ($EOMIn6_{grassland}$), harvesting losses on maize land ($EOM_{mizelandharvestloss}$), crop residues on grassland ($EOMIn7_{grassland}$) and crop residues on arable land ($EOM_{cropresiduearableland}$) are assumed to be benefit the crops from which they originate. That this is not reality in every phase of a crop rotation is ignored here.

The item EOMIn8 (effective organic matter in the form of catch crops and green manures) only relates to the organic matter balance of arable land, as follows:

EOMIn8 = ((SO x PV x $In8_{maize\ land}$ x OM / $N_{catch\ crop}$ x $HC_{fresh\ crop}$) + ((BO-SO) x FG x $EOM_{green\ manure}$)) / BO

Where
SO = maize land area, FV = fraction of maize land sown with a catch crop, $In8_{maize\ land}$ = 40 kg N per ha, OM / $N_{catch\ crop}$ = 45, $HC_{fresh\ crop}$ = 0.25, BO = arable land area, FG = fraction of the non-maize arable land sown with a green manure crop, $EOM_{green\ manure\ crop}$ = 1000 kg per ha (Table 2.5.22).

Table 2.5.21 *Input and output items for determining the organic matter balance (kg effective OM / ha) with indication ('X') whether the input data relate to the farm as a whole, to crops (grassland, arable land) or on crops with a distinction between the part that is grown in rotation and the part that is grown in continuous cropping.*

Input/ output	Code	Item	Level	
			Farm	Grassland, Arable land
Input	EOMIn1	Pasture manure		X
	EOMIn2	'Stable manure', excluding feed leftovers roughage		X
	EOMIn2 feed leftover	Feed leftovers		X
	EOMIn6	Grazing, cutting and harvesting losses		X
	EOMIn7	Crop residues		X
	EOMIn8	Catch crops and green manures		X

Table 2.5.22 *Effective organic matter contribution (EOM, kg per hectare per year) of some arable crops and green manures (source: after Timmer et al., 2004).*

Crop	Crop residue	By-product
WPS grains	1650	-
Lucerne	1350	-
Red clover	1350	-
Beets	400	1000
Maize	700 *	1350 ****
Grains, coarse grain	700	1350
Grains, small grain	1650	850
Grass seed	2500 **	500
Legumes	500	500
Potatoes	900 ***	-
Seed potatoes	900	-
Onions and bulbs	300	-
Leafy vegetables	450	-
Non-leafy vegetables	600	150
Other	1700	-
Green manure	1000	-

* In practice, the contribution of the 'by-product' (straw) of 1350 kg per hectare will be added.

** Average of various grass seed types and including straw.

*** Including 100 kg per hectare of baby potatoes.

**** Estimated as a product of 6000 kg dry matter per hectare, of which 90% organic matter and a humidification coefficient of 25%.

2.5.7 Comments on BEC

- The CO_2 released as a result of fossil fuel use by 'non-ruminants' (pigs, chickens, veal calves) on-farm or 'upstream' (via purchased feed), is not yet included in ANCA. This means that the total emission of CO_2 equivalents is underestimated when 'non-ruminants' are present.
- With regard to N and P, ANCA is mainly limited to losses and efficiencies within the boundaries of the farm. However, by not considering emissions taking place outside the farm, a comparison of farms can lead to a skewed picture. This applies in particular to emissions for which not the local environmental impact (nitrate and ammonium, phosphate, ammonia), but the global environmental impact is relevant: namely the emission of CO_2 equivalents. That is why greenhouse gas emissions

resulting from off-farm production processes (synthetic fertilizers, purchased feed materials, energy) are also include in ANCA.

- With regard to the (effective) organic matter balance, the following should be noted. As a rule of thumb, it is assumed that the balance must be 1250-2500 kg of effective organic matter per hectare per year. This is based on the idea that a liter of soil weighs approximately 1300 grams, the topsoil is 25-30 cm thick, a soil contains 2-3% more or less stable organic matter and degrades approximately 2% of this annually (Kortleven, 1963). Since this rule of thumb has many assumptions, this also means that a balance of less than 1250-2500 kg per ha does not necessarily indicate a decrease in the organic matter content of the soil. Likewise, a balance of more than 1250-2500 kg per ha does not necessarily indicate an increase in organic matter content. Ideally, the supplementation required to maintain the organic matter content at a certain level should not be determined based on the rule of thumb, but farm-specific as a function of the desired level. The required supplementation can then be compared with the realization, from which we can deduce whether the organic matter content tends to decrease or increase. The outcome of this may be a reason to (re) sample the soil. Vigilance is also required in this case because correct sampling is difficult due to changes in the density of the soil, sampling depth in relation to changed tillage methods, and contamination of deeper soil layers with soil material from higher layers during sampling. Conclusions about the fate of N and P linked to the organic matter can be drawn only if repeated, multi-year analyzes show a systematic pattern.
- With regard to the contribution to the organic matter supply per kg of manure-N or per cubic meter of manure, only three types of manure are distinguished. With regard to manure from ruminants and non-ruminants, the values were derived from the characteristics of liquid manure. Because solid manures contain a lot more C per kg N and per cubic meter, ANCA underestimates the organic matter supply when using solid manure.

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Appendix 1 Key figures for feed ingredients

The dry matter content per feed material (DM), the crude ash content (CA), the digestibility of crude protein (DCCP) (see section 2.2.2.2), the digestibility of the organic matter (DCOM), the methane emissions from feed components of the dairy herd including young stock (g CH_4 per kg DM) depending on the share of maize silage (CS) in rations (%) (see section 2.5.6.1) and the emission (CO_2 equivalents per kg product) of purchased feed ingredients (excluding transport) (see paragraph 2.5.6.8) for the different feed ingredients, divided into feed types and subgroups.

Name	Feed type [1]	DM (g / kg)	CA (g / kg)	DCCP [2]	DCOM	g CO2-eq / kg [3]	EF CH_4 at 0% CS	EF CH_4 at 40% CS	EF CH_4 at 80% CS
							g / kg DM	g / kg DM	g / kg DM
Grass silage	GK	472	55	-[4]	0.76	241	-[4]	-[4]	-[4]
Grass hay	GK	845	84	-[4]	0.7	409	-[4]	-[4]	-[4]
Grass dried (bales)	GK	918	106	-[4]	0.78	2282	-[4]	-[4]	-[4]
Grass dried (pellets)	GK	920	117	-[4]	0.73	2349	-[4]	-[4]	-[4]
Other grass product	GK	789	91	-[4]	0.74	1320	-[4]	-[4]	-[4]
Compound feed	KV	894	67	-[4]	0.85	1399	-[4]	-[4]	-[4]
Maize silage	SM	283	14	-[4]	0.73	52	-[4]	-[4]	-[4]
Maize silage dried	SM	909	49	-[4]	0.73	1464	-[4]	-[4]	-[4]
Other maize silage	SM	596	32	-[4]	0.73	758	-[4]	-[4]	-[4]
Pasturing	VG	160	17	0.82	0.84	76	19.2	19.2	19.2
Summer barn feeding	VG	160	17	0.82	0.84	76	23.3	23.3	23.3
Potato chips	KV	969	35	0.24	0.85	461	12.07	12.26	11.38
Potato protein	KV	906	14	0.89	0.89	1304	16.43	14.76	14.04
Potatoes dried	KV	897	42	0.39	0.85	461	22.74	21.51	20.49
Potato pulp	KV	877	59	0.32	0.82	522	21.65	21.22	20.45
Potato starch dried	KV	855	4	0.99	0.94	653	23.98	22.33	20.16
Sweet potatoes dried	KV	878	38	-0.01	0.85	1507	24.55	23.57	22.13
Bone meal	KV	954	462	0	0	304	20	20	20
Brewer’s grains dried	KV	903	44	0.75	0.65	428	16.74	16.43	16.27
Brewer’s yeast dried	KV	936	69	0.82	0.78	444	19.75	18.63	18.6
Beet pulp	KV	907	72	0.64	0.87	350	25.76	25.8	28.31
Blood meal	KV	937	17	0	0	1112	18.27	16.67	16.77
Buckwheat	KV	865	24	0.74	0.69	1310	20	20	20
Beans (Phas) heated	KV	862	52	0.78	0.89	1625	21.29	20.87	21.38
Bread meal	KV	900	29	0.77	0.89	112	22.97	23.54	23.2
Casein	KV	912	34	0.95	0.95	6397	18.27	16.68	16.78
Citrus pulp	KV	908	61	0.49	0.86	695	26.98	26.43	28
Peas dry	KV	867	28	0.83	0.9	415	22.84	21.99	22.13
Phytase	KV	1000	0	0	0.83	2000	0	0	0
Barley	KV	869	21	0.75	0.85	429	22.8	22.07	20.74
Barley feed meal hg	KV	875	53	0.79	0.73	318	19.66	19.19	18.72
Barley mill byproduct	KV	887	60	0.73	0.67	318	19.11	18.64	18.08
Millet	KV	897	29	0.71	0.8	1181	20.89	18.74	17.26
Grass meal	KV	920	117	0.64	0.73	2339	20.12	19.94	20.66
Grass seed	KV	863	47	0.63	0.61	1398	22.29	21.5	19.92
Groundnut with shell	KV	942	28	0.86	0.79	2143	8.42	9.13	11.51
Groundnut without shell	KV	932	22	0.87	0.93	4553	3.59	4.02	5.6
Groundnut expeller partly shell	KV	915	64	0.9	0.84	1429	17.63	17.72	20.03

Name	Feed type [1]	DM (g / kg)	CA (g / kg)	DCCP [2]	DCOM	g CO2-eq / kg [3]	EF CH_4 at 0% CS	EF CH_4 at 40% CS	EF CH_4 at 80% CS
							g / kg DM	g / kg DM	g / kg DM
Groundnut expeller with shell	KV	933	34	0.88	0.77	1294	14.06	14.7	17.2
Groundnut expeller without shell	KV	914	68	0.91	0.87	1429	18.05	17.96	20.11
Groundnut meal partly shell	KV	893	54	0.92	0.81	1175	17.8	17.96	20.33
Groundnut meal with shell	KV	913	60	0.91	0.85	1175	21	20.85	23.26
Oats	KV	889	26	0.74	0.77	487	19.66	19.78	19.76
Oats peeled	KV	884	19	0.8	0.9	665	21.08	20.8	20.42
Oats husk meal	KV	907	43	0.47	0.54	224	17.26	17.81	18.05
Oats mill feed hg	KV	886	24	0.71	0.75	444	18.92	19.22	19.35
Hemp seed	KV	913	48	0.75	0.62	6707	9.88	9.96	11.33
Carob	KV	891	30	0.02	0.74	593	27.2	26.05	26.35
Chalk grit	KV	990	980	0	0.83	513	0	0	0
Cottonseed with husk	KV	911	40	0.73	0.68	983	17.78	16.84	16.91
Cottonseed without husk	KV	935	44	0.8	0.84	1398	10.38	10.09	11.31
Cotton seed meal expeller partly with husk	KV	941	57	0.78	0.69	800	15.89	15.94	17.4
Cotton seed meal expeller with husk	KV	921	52	0.77	0.66	657	15.81	16.03	17.58
Cotton seed meal expeller without husk	KV	928	61	0.8	0.74	1008	13.94	13.96	15.36
Cotton seed meal extracted partly with husk	KV	892	64	0.79	0.68	720	17.51	17.69	19.87
Cotton seed meal extracted with husk	KV	945	50	0.77	0.66	587	17.95	18.18	20.35
Cotton seed meal extracted without husk	KV	897	66	0.8	0.72	914	17.36	17.4	19.51
Coconut copra cake	KV	909	61	0.72	0.81	946	18.71	19.08	20.92
Coconut copra meal	KV	898	65	0.73	0.8	946	20.8	21.18	23.22
Chalk (finely milled)	KV	990	980	0	0.83	1219	0	0	0
Linseed	KV	913	41	0.8	0.82	1402	8.56	9	10.72
Linseed expeller	KV	901	55	0.85	0.77	830	18.44	18.58	21.03
Linseed meal	KV	870	54	0.85	0.77	754	20.63	20.65	23.16
Lentils	KV	874	30	0.84	0.88	1412	22.26	20.9	19.81
Lupins	KV	901	33	0.9	0.91	1159	21.36	20.98	22.7
Lucerne (alfalfa) meal	KV	911	104	0.67	0.65	1557	20.04	20.23	21.65
Magnesium Oxide	KV	1000	0	0	0.83	1058	0	0	0
Maize	KV	872	12	0.62	0.9	589	21.16	19.69	17.83
Maize chemical/heat treated	KV	879	13	0.63	0.9	594	22.65	22.91	21.17
Maize gluten meal	KV	901	17	0.95	0.94	1257	16.64	15.22	13.34
Maize gluten feed	KV	892	61	0.77	0.83	1582	20.34	19.76	19.37
Maize germ meal solvent extracted	KV	887	37	0.75	0.83	371	21.07	21.53	23.7
Maize germ meal feed expeller	KV	897	44	0.69	0.85	439	20.17	19.83	20.06
Maize germ meal feed solvent extracted	KV	875	39	0.7	0.85	259	21.2	21.54	23.47

Name	Feed type [1]	DM (g / kg)	CA (g / kg)	DCCP [2]	DCOM	g CO2-eq / kg [3]	EF CH_4 at 0% CS	EF CH_4 at 40% CS	EF CH_4 at 80% CS
							g / kg DM	g / kg DM	g / kg DM
Maize distillers solubles dried	KV	901	51	0.76	0.82	279	19.43	20.05	22.87
Maize feed meal	KV	877	14	0.62	0.88	554	21.91	20.56	18.7
Maize feed meal solvent extracted	KV	868	17	0.64	0.88	554	22.39	21.43	20.54
Maize bran	KV	873	14	0.66	0.78	1089	22.14	21.43	20.54
Maize starch	KV	876	1	0	0.96	932	23.92	21.99	22.72
Monocalcium Phosphate	KV	980	960	0	0.83	569	0	0	0
Malt culms	KV	917	62	0.76	0.71	0	21.58	20.74	21.47
Sodium bicarbonate	KV	1000	0	0	0.83	485	0	0	0
Niger seed	KV	916	47	0.8	0.76	3045	7.59	7.26	7.65
Horse beans	KV	863	34	0.84	0.9	536	21.99	21.6	22.89
Horse beans white	KV	872	35	0.85	0.9	391	21.92	21.44	22.58
Palm kernel expeller	KV	937	44	0.74	0.75	641	16.87	17.38	18.58
Palm kernel solvent extracted	KV	880	40	0.75	0.74	641	19.72	20.85	23.51
Palm kernels	KV	938	20	0.62	0.86	2800	2.67	3.57	4.4
Premix	KV	1000	0	0.75	0.83	1176	0	0	0
Rape seed extruded	KV	890	76	0.85	0.78	797	18.88	19.36	22.7
Rape seed	KV	923	39	0.78	0.83	2397	4.88	5.68	7.91
Rape seed expeller	KV	894	70	0.84	0.79	894	17.48	17.9	20.94
Rape seed meal	KV	872	67	0.84	0.75	1049	17.94	17.86	18.61
Rice with hulls	KV	886	44	0.47	0.75	2121	18.77	18.1	16.97
Rice without hulls	KV	872	7	0.49	0.91	2711	22.73	21.29	19.68
Rice husk	KV	911	152	0.43	0.42	275	11.99	12.41	12.18
Rice bran meal, solvent extracted	KV	899	119	0.65	0.71	466	15.95	15.64	15.05
Rice feed meal	KV	903	94	0.63	0.79	460	13.32	12.95	12.25
Rye	KV	872	16	0.74	0.87	445	23.72	23.32	22.9
Rye feed	KV	872	50	0.77	0.78	401	20.05	20.44	22.07
Safflower seed	KV	907	28	0.68	0.45	1621	7.71	8.91	11.64
Sesame seed	KV	942	75	0.83	0.85	1908	6.61	6.68	7.85
Sesame seed expeller	KV	946	126	0.9	0.85	710	15.43	14.99	16.2
Sesame seed meal solvent extracted	KV	929	62	0.89	0.81	593	21.54	20.67	21.88
Soya protein concentrate	KV	920	0	0.9	0.9	7018	0	0	0
Soya bean not heat treated	KV	885	49	0.89	0.88	3605	15.31	15.26	17.5
Soya bean hulls	KV	885	47	0.6	0.84	2419	23.34	22.95	23.56
Soya bean heat treated	KV	885	49	0.89	0.88	3609	15.07	15.03	17.33
Soya bean expeller	KV	888	64	0.91	0.91	4582	18.43	18.15	20.32
Soya bean meal resistent	KV	872	62	0.89	0.9	4469	20.4	19.25	18.86
Soya bean meal, dehulled	KV	874	63	0.91	0.91	4419	21.11	20.5	22.36
Sorghum	KV	882	15	0.51	0.85	1014	21.24	19.76	17.86
Sorghum gluten meal	KV	900	32	0.89	0.89	812	18.3	17.29	16.17
Sugar	KV	1000	0	0	1	528	34.09	31.06	28.52
Tapioca dried	KV	880	56	-0.5	0.84	834	23.9	23.14	21.96
Tapioca starch	KV	880	1	1	0.94	1026	24.92	23.43	20.86
Wheat	KV	868	15	0.75	0.89	449	23.35	22.97	22.52
Wheat gluten meal	KV	930	9	0.96	0.95	2949	17	15.74	16.21

Name	Feed type [1]	DM (g / kg)	CA (g / kg)	DCCP [2]	DCOM	g CO2-eq / kg [3]	EF CH_4 at 0% CS	EF CH_4 at 40% CS	EF CH_4 at 80% CS
							g / kg DM	g / kg DM	g / kg DM
Wheat gluten feed	KV	906	52	0.69	0.78	610	20.76	20.35	19.75
Wheat middlings	KV	865	50	0.78	0.74	271	20.41	20.58	22.01
Wheat germ feed	KV	873	40	0.86	0.84	818	19.93	19.91	21.1
Wheat feed flour	KV	867	26	0.81	0.87	271	21.93	21.79	22.1
Wheat feed meal	KV	868	45	0.79	0.77	271	20.86	20.92	22.08
Wheat bran	KV	883	55	0.76	0.69	443	20.23	20.3	21.74
Triticale	KV	877	17	0.74	0.89	495	23.65	23.29	23.09
Urea	KV	1000	0	1	0.83	1336	0	0	0
Fat from animals	KV	994	1	0	0.9	1255	-11.73	-10.94	-11.19
Fat / oil vegetable	KV	995	0	0	0.95	3841	-11.75	-10.95	-11.21
Feather meal	KV	934	23	0	0	397	0	0	0
Fish meal	KV	919	153	0	0	1277	16.64	15.22	13.34
Meat-and-bone meal	KV	948	378	0	0	304	16.64	15.22	13.34
Chicory pulp dried	KV	897	79	0.57	0.84	567	25.01	25.19	27.86
Sea sand dried	KV	1000	0	0	0	2	0	0	0
Sunflower seed partly dehulled	KV	914	30	0.81	0.73	866	7.14	7.99	10.14
Sunflower seed not dehulled	KV	914	27	0.76	0.57	1117	4.62	5.57	7.02
Sunflower seed dehulled	KV	940	34	0.82	0.85	1100	6.47	6.66	8.26
Sunflower seed expeller partly dehulled	KV	921	62	0.86	0.63	475	14.01	14.61	17.13
Sunflower seed expeller not dehulled	KV	913	43	0.83	0.45	437	9.78	10.68	12.61
Sunflower seed expeller dehulled	KV	906	54	0.89	0.74	520	16.71	17.1	19.88
Sunflower seed meal	KV	890	65	0.88	0.68	442	17.94	18.39	21.22
Salt	KV	998	996	0	0	174	0	0	0
Other grain	KV	896	32	0.75	0.76	568	15.95	15.71	15.97
Other legume	KV	886	34	0.86	0.88	839	19.16	18.76	19.87
Other dry by-product	KV	899	52	0.75	0.76	1183	17.94	17.69	18.34
Other minerals	KV	990	282	0.75	0.83	1176	0	0	0
Artificial milk	MP	963	48	0.91	0.93	5278	26.66	26.45	26.96
Milkpowder skimmed	MP	945	79	0.92	0.95	15252	25.63	28.84	30.11
Milkpowder whole	MP	949	63	0.9	0.95	13622	16.52	15.24	14.53
Whey powder	MP	980	80	0.77	0.94	661	29.64	27.83	27.95
Whey powder (wet 60%)	MP	600	0	0.77	0.94	129	29.64	27.83	27.95
Whey powder (wet 30%)	MP	300	0	0.77	0.94	21	29.64	27.83	27.95
Whey powder (wet 6%)	MP	60	0	0.77	0.94	0	29.64	27.83	27.95
Whey powder delac	MP	958	201	0.88	0.93	987	22.77	21.77	22.77
Whey powder delac (wet 60%)	MP	600	0	0.88	0.94	129	29.64	27.83	27.95
Whey powder delac (wet 30%)	MP	300	0	0.88	0.94	21	29.64	27.83	27.95
Whey powder delac (wet 6%)	MP	60	0	0.88	0.94	0	29.64	27.83	27.95
Cheese whey	MP	44	5	0.86	0.94	0	26.71	26.61	30.03
Other milk product	MP	589	40	0.85	0.94	3008	27.15	26.14	26.67
Potato juice concentrated	OV	575	183	0.91	0.93	66	20.06	21.72	26.74
Potato pulp pressed	OV	159	6	0.38	0.84	24	24.04	24.31	26.04
Potato peelings ensiled	OV	220	18	0.5	0.85	0	19.43	19.43	19.43

Name	Feed type [1]	DM (g / kg)	CA (g / kg)	DCCP [2]	DCOM	g CO2-eq / kg [3]	EF CH_4 at 0% CS	EF CH_4 at 40% CS	EF CH_4 at 80% CS
							g / kg DM	g / kg DM	g / kg DM
Potato cuttings/chips raw	OV	218	7	0.43	0.88	0	22.22	21.17	20.5
Potato peelings steamed	OV	140	9	0.61	0.88	0	23.24	24.9	28.08
Potato starch wet	OV	262	9	0.57	0.9	0	22.6	21.33	19.85
Potato starch, puffed	OV	455	8	0.99	0.93	0	22.93	21.36	19.18
Endive	OV	52	9	0.85	0.86	0	20	20	20
Apples	OV	157	4	-0.2	0.88	0	20	20	20
Pickle	OV	49	4	0.63	0.79	0	20	20	20
Brewer’s grains	OV	241	11	0.8	0.64	0	15.69	15.5	15.5
Beet leaf	OV	175	55	0.58	0.71	0	20	20	20
Beet leaf and top	OV	160	32	0.79	0.82	0	20	20	20
Sugarbeet pulp pressed ensiled	OV	218	16	0.65	0.88	1	24.62	24.53	26.17
Sugarbeet rests ensiled	OV	136	26	0.53	0.77	63	20	20	20
Bean straw (vicia)	OV	840	61	0.46	0.51	73	17	17	17
Bean straw (phas)	OV	863	98	0.62	0.61	146	17	17	17
CCM part core	OV	584	11	0.58	0.86	235	20.45	19.14	17.29
CCM with core	OV	512	10	0.58	0.84	206	20.55	19.36	17.52
CCM without core	OV	624	10	0.58	0.87	251	20.54	19.17	17.29
Pea straw	OV	841	84	0.58	0.49	135	17	17	17
Barley straw	OV	860	74	0.17	0.47	208	17	17	17
Whole crop silage (cereal)	OV	373	29	0.53	0.68	124	20	20	20
Distillers’ grains (DDG)	OV	72	4	0.84	0	0	17.62	17.62	17.62
Grass seed straw	OV	844	64	0.36	0.54	57	17	17	17
Oats straw	OV	840	59	0.19	0.5	245	17	17	17
Clover red hay	OV	830	83	0.61	0.59	206	19.53	19.48	20.99
Clover red ensiled	OV	378	59	0.71	0.66	99	19.53	19.48	20.99
Clover red dried	OV	901	130	0.62	0.68	1400	19.53	19.48	20.99
Clover red straw	OV	830	56	0.44	0.42	206	19.53	19.48	20.99
Cucumber	OV	58	6	0.57	0.8	0	20	20	20
Cabbage (winterrape)	OV	100	15	0.87	0.83	0	20	20	20
Cabbage (cauliflower)	OV	72	10	0.91	0.9	0	20	20	20
Cabbage (marrowstem)	OV	120	16	0.84	0.83	0	20	20	20
Cabbage (red/white/sav.)	OV	85	5	0.82	0.83	0	20	20	20
Cabbage (brussels sprouts)	OV	162	14	0.88	0.88	0	20	20	20
Turnips	OV	110	14	0.67	0.88	0	20	20	20
Beetroot	OV	114	11	0.67	0.89	0	20	20	20
Lucerne (alfalfa) hay	OV	851	88	0.67	0.61	211	19.53	19.48	20.99
Lucerne (alfalfa) ensiled	OV	403	59	0.72	0.64	100	19.53	19.48	20.99
Lucerne dried	OV	910	109	0.69	0.65	1449	19.53	19.48	20.99
Maize gluten feed silage	OV	418	16	0.72	0.83	546	20.97	20.16	19.09
Whole Ear Corn Silage	OV	531	11	0.57	0.83	227	20.51	20.51	20.51
Maize straw	OV	840	86	0.27	0.57	0	17	17	17
Maize solubles	OV	480	85	0.87	0.91	1357	21.99	23.32	28.47
Molasses sugarbeet	OV	723	60	0.75	0.9	113	30.01	28.71	30.7
Molasses sugarcane	OV	732	101	0.13	0.81	298	29.8	22.07	21.16
Paprika	OV	125	8	0.56	0.72	0	20	20	20
Pears	OV	165	4	-0.93	0.87	0	20	20	20
Leeks	OV	100	10	0.8	0.83	0	20	20	20

Name	Feed type [1]	DM (g / kg)	CA (g / kg)	DCCP [2]	DCOM	g CO2-eq / kg [3]	EF CH_4 at 0% CS	EF CH_4 at 40% CS	EF CH_4 at 80% CS
							g / kg DM	g / kg DM	g / kg DM
Rye straw	OV	840	59	0.14	0.46	189	17	17	17
Lettuce	OV	61	11	0.82	0.85	0	20	20	20
Green cereals silage	OV	250	43	0.6	0.71	82	19.53	19.48	20.99
Spinach	OV	94	17	0.84	0.85	0	20	20	20
Brussels sprouts leaf & stalk	OV	180	20	0.85	0.84	0	20	20	20
Sugarbeets fresh	OV	260	49	0.27	0.9	41	25	25	25
Wheat straw	OV	902	90	0.23	0.42	245	17	17	17
Tomatoes	OV	63	6	0.76	0.81	0	20	20	20
Onions / bulbs	OV	100	13	0.75	0.9	0	20	20	20
Field beans ensiled	OV	323	29	0.68	0.64	370	21.4	21.4	21.4
Vinasse sugarbeet	OV	680	157	0.86	0.9	388	21.76	22.8	27.02
Fodder beet	OV	129	21	0.6	0.9	44	25	25	25
Fodder beet cleaned	OV	143	13	0.63	0.9	50	25	25	25
Potatoes	OV	350	32	0.48	0.88	188	19.95	19.95	19.95
Chicory foliage	OV	175	60	0.34	0.58	0	20	20	20
Chicory press pulp	OV	232	23	0.53	0.84	0	24.79	24.49	25.73
Chicory root forced clean	OV	149	12	0.61	0.85	0	20	20	20
Chicory root forced dirt	OV	122	21	0.61	0.85	0	20	20	20
Chicory root not forced	OV	200	20	0.49	0.92	0	20	20	20
Carrots	OV	113	11	0.57	0.9	0	20	20	20
Carrot peelings steamed	OV	55	7	0.63	0.9	0	24.67	23.93	24.65
Other grain straw	OV	861	71	0.18	0.46	222	17	17	17
Other leafy vegetables	OV	110	14	0.67	0.88	0	20	20	20
Other vegetables	OV	144	36	0.46	0.74	0	20	20	20
Other roughage	OV	499	47	0.52	0.68	123	19.43	19.31	19.41
Other wet by-product	OV	217	25	0.68	0.83	75	21.35	21.11	21.6

[1] GK = grass silage; VG = fresh grass; SM = maize silage; KV = concentrates; MP = Milk powder; OV = Other roughage and by-products

[2] CVB 2004, CVB 2006, CVB 2011 and http://www.cvbdiervoeding.nl/pagina/10081/downloads.aspx

[3] per kg of product; Feedprint version 2015.03 (Vellinga *et al.* , 2013), excluding transport to the farm

[4] is calculated, see main text

Appendix 2 Emission coefficients

Carbon dioxide emissions (direct and indirect) through the use of various products and processes in the dairy farm's operations. Emission coefficients expressed in CO_2 equivalents per unit displayed.

Process	Product	Specification	Emission coefficient	Unit	Source
Supply	Synthetic fertilizer	ammonium	3099	g CO_2-eq / kg pure N	Feedprint
Supply	Synthetic fertilizer	nitrate	3625	g CO_2-eq / kg pure N	Feedprint
Supply	Synthetic fertilizer	urea	1332	g CO_2-eq / kg pure N	Feedprint
Supply	Synthetic fertilizer	nitrogen combinations	6685	g CO_2-eq / kg pure N	Feedprint
Supply	Synthetic fertilizer	phosphate	1218	g CO_2-eq / kg pure P_2O_5	Feedprint
Supply	Synthetic fertilizer	potassium	563	g CO_2-eq / kg pure K_2O	Feedprint
Supply	Synthetic fertilizer	lime, limestone	32	g CO_2-eq / kg limestone	Note Vellinga
Supply	Synthetic fertilizer	lime, dolomite	44	g CO_2-eq / kg dolomite	Note Vellinga
Supply	Litter	straw	245	g CO_2-eq / kg	Feedprint
Supply	Litter	sawdust	22	g CO_2-eq / kg	Agri footprint
Supply	Litter	lime	32	g CO_2-eq / kg	Agri footprint
Supply	Litter	other	100	g CO_2-eq / kg	Agri footprint
Supply	Cattle	cows	10,629	kg CO_2-eq / kg live weight	Agri footprint
Supply	Cattle	heifers	10,629	kg CO_2-eq / kg live weight	Agri footprint
Supply	Cattle	calves	10,667	kg CO_2-eq / kg live weight	Agri footprint
Supply	Cattle	Nursing calf	10,667	kg CO_2-eq / kg live weight	Agri footprint
Supply	Pesticide	nematicide	10183	g CO_2-eq / kg ash	Ecoinvent 3
Supply	Pesticide	herbicide	11541	g CO_2-eq / kg ash	Ecoinvent 3
Supply	Pesticide	fungicide	5791	g CO_2-eq / kg ash	Ecoinvent 3
Supply	Pesticide	others	9867	g CO_2-eq / kg ash	Feedprint
Supply	Cover material	plastic	3053	g CO_2-eq / kg	Ecoinvent 3
Energy use	Drying	grass bale	404	kg CO_2-eq / ton input	Feedprint
Energy use	Drying	grass pellet	470	kg CO_2-eq / ton input	Feedprint
Energy use	Drying	maize silage	366	kg CO_2-eq / ton input	Feedprint
Energy use	Drying	other roughage	332	kg CO_2-eq / ton input	Feedprint
Energy use	Burning	diesel	72.5	g CO_2-eq / MJ	Zijlema 2019
Energy use	Burning	natural gas	56.6	g CO_2-eq / MJ	Zijlema 2019
Energy use	Burning	biogas	0	g CO_2-eq / MJ	Zijlema 2019
Energy use	Burning	propane	66.7	g CO_2-eq / MJ	Zijlema 2019
Energy use	Burning	fuel oil	77.4	g CO_2-eq / MJ	Zijlema 2019
Energy use	production	electric normal	200.4	g CO_2-eq / MJ	Simapro
Energy use	production	electric green	13.3	g CO_2-eq / MJ	Simapro
Energy use	production	diesel	12.3	g CO_2-eq / MJ	Simapro
Energy use	production	natural gas	19.9	g CO_2-eq / MJ	Simapro
Energy use	production	biogas	24.5	g CO_2-eq / MJ	Simapro
Energy use	production	propane	18.6	g CO_2-eq / MJ	Simapro
Energy use	production	oil	11.5	g CO_2-eq / MJ	Simapro
Energy use	indirectly	electricity	200.4	g CO_2-eq / MJ	Feedprint
Energy use	indirectly	gas	68.3	g CO_2-eq / MJ	Feedprint
Energy use	indirectly	kerosene	92.8	g CO_2-eq / MJ	Feedprint
Energy use	indirectly	coal	134.6	g CO_2-eq / MJ	Feedprint
Energy use	supply	water	358	g CO_2-eq / m3	Ecoinvent 3

Process	Product	Specification	Emission coefficient	Unit	Source
Energy use	Electricity production	biomass	12.78	g CO_2-eq / MJ	Simapro
Energy use	Electricity production	wind	3.79	g CO_2-eq / MJ	Simapro
Energy use	Electricity production	Sun	22.77	g CO_2-eq / MJ	Simapro
Application	lime	lime, dolomite	120	g CO_2-eq-C / kg	Note Vellinga
Application	lime	lime, limestone	130	g CO_2-eq-C / kg	Note Vellinga
Application	urea	-	200	g CO_2-eq-C / kg	Feedprint

To explore the potential of nature to improve the quality of life

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