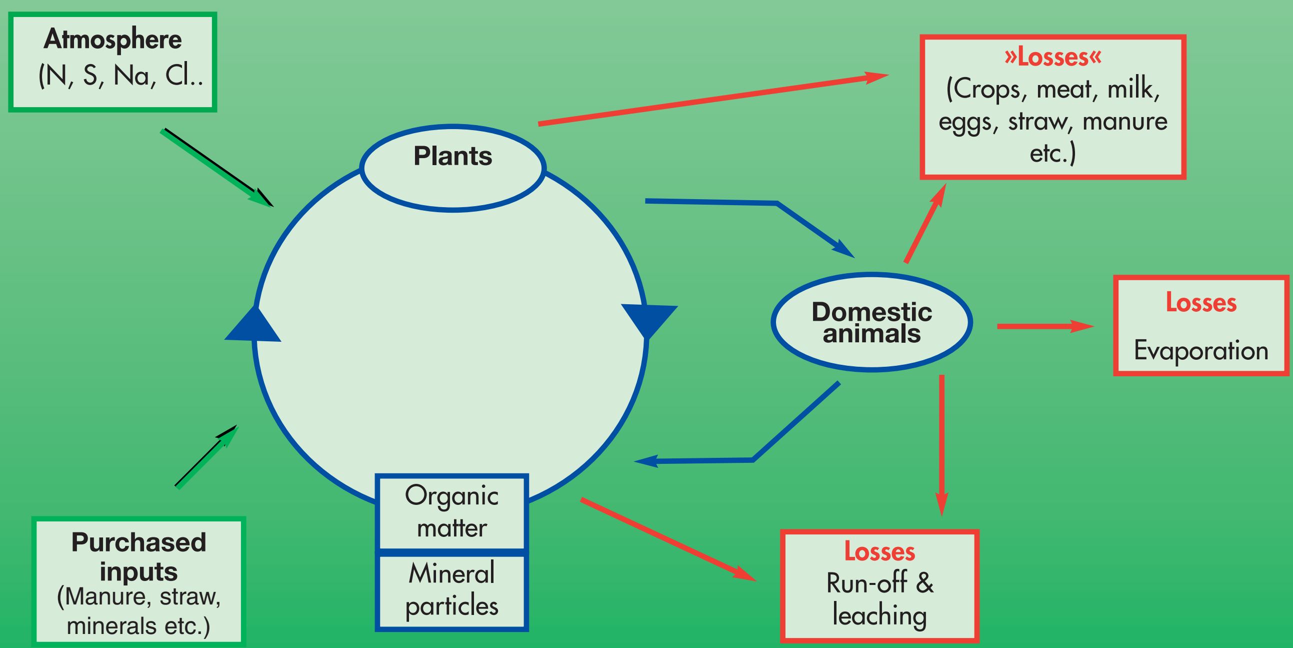
4. Farm Nutrient Balance

Careful nutrient management is an essential part of organic farming. Nutrient leaching should be minimal, and nitrogen losses should not exceed the nitrogen input from biological N-fixation.
A large share of the nutrients leaving the farm as sold products should be recycled from the consumers to the land. Local food trade should be encouraged, thus saving energy used for transportation.
The envisioned goal may be an ideal. But an organic farmer must make a big effort to limit nutrient losses and to effectively distribute the farm's nutrients within the crop rotation.



Nutrient cycle in agriculture
The nutrient cycle in agriculture differs from »natural« nutrient cycles. Selling products means losing nutrients from the farm. In addition, there are conciderable losses through evaporation, run-off and leaching.

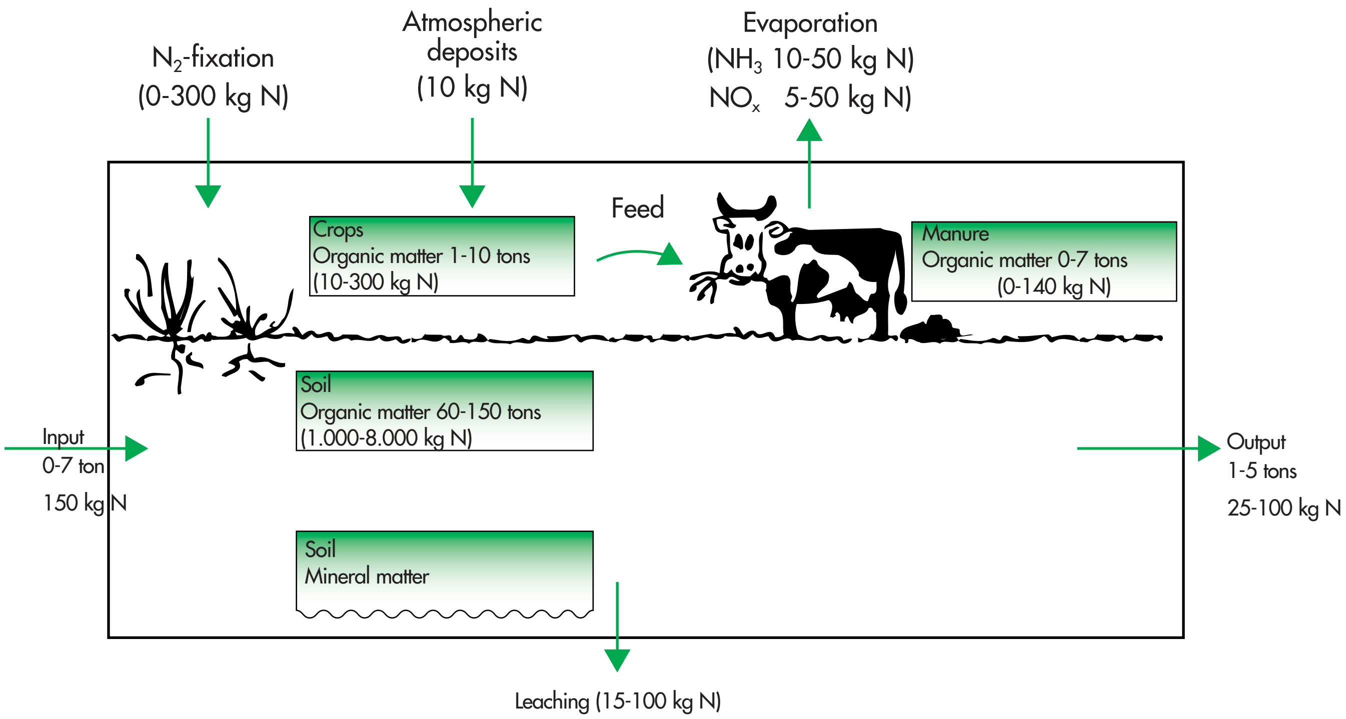
The farm's nutrient balance

One of the main challenges for an organic farmer is securing the crops' nutrient supply. If there is a lack of nutrients in the fertilizer management plan or if crops show signs of nutrient deficiency, you can't just go and buy nutrients at the local agricultural cooperative. Long-term planning and measures are needed. Shortages must be prevented, since there are few remedies once a problem has occurred.

All of the farm's nutrient resources must be seen as a whole. Naturally, the individual parts of the entire farm should be optimised, but nevertheless, all elements are linked together.
Nutrient resources that can be utilised by organic farmers include:

- Soil (soil nutrient pool)
- Atmosphere
- Purchased fertilizer, feed, straw, minerals, etc.
- Standing crops, including green manure
- Farmyard manure

This is illustrated in the figure below. Here, nitrogen is used as an example of how an important nutrient enters and leaves a farm.



Nutrient cycling
The figures are typical for organic farms in Denmark, but vary a lot between different types of production. The amount of organic matter is shown as t/ha, figures for nitrogen show kg N/ha.

This chapter presents an overview of what farmers can do to affect the cycling of nutrients on a farm. The objective is to get an understanding of how to regulate the various elements of a nutrient cycle in order to obtain strong crops that can withstand weeds and pests. The bottom line is naturally ensuring high yields.

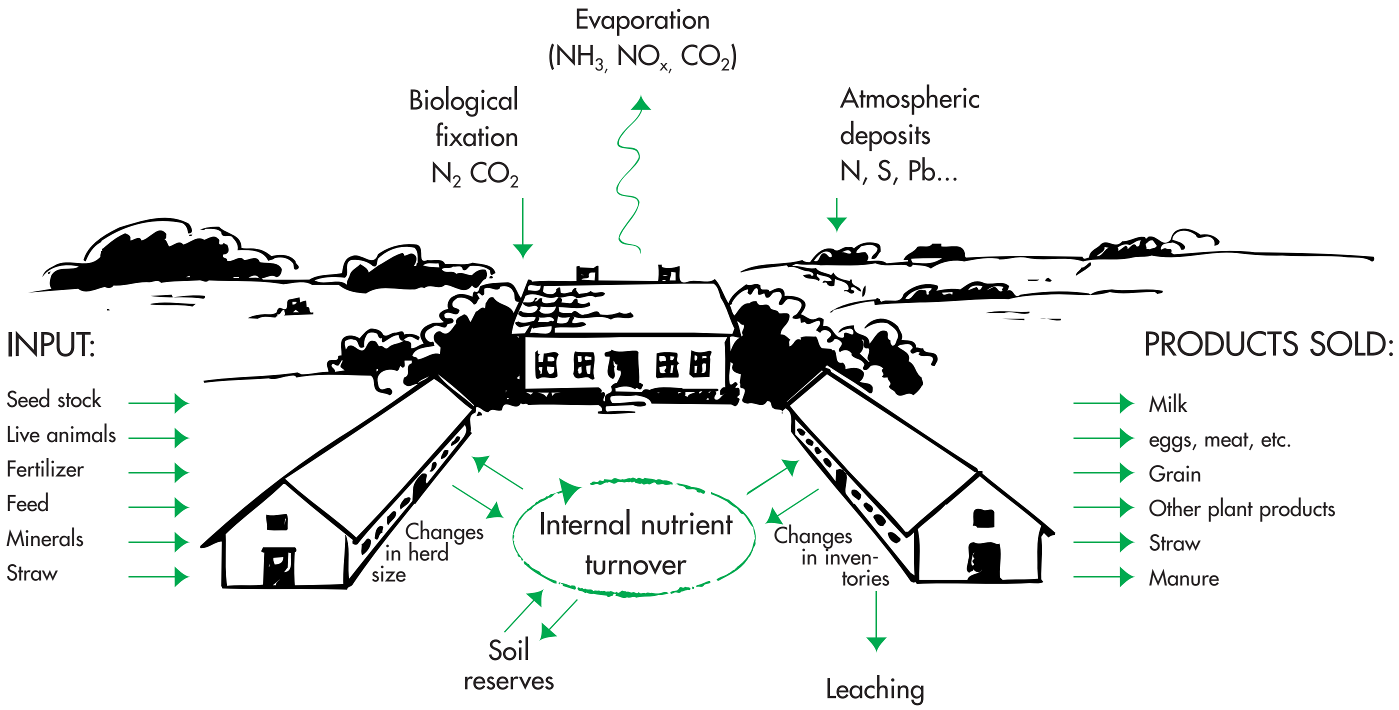
One good way to get an overview is to consider the total nutrient balance of a farm. Imagine that you are standing at the farm gate, and are recording all nutrients entering and leaving the farm in the course of a year.

Then you can evaluate if the farm as a whole is reasonably in balance in relation to the surrounding natural environment and society. Comparisons with results from other farms will give you an idea of how to make adjustments on your farm.
Finally, you can analyse the distribution of nutrients within the farm itself.

In practical terms, one calculates a farm's net nutrient balance. This figure can be negative. This is usually done for the nutrients N, P and K. For these calculations, a spreadsheet can be used, e.g., one that can be downloaded from this book's website, see the Chapter "More knowledge".

In order to calculate a whole-farm nutrient balance, certain data are needed, such as the amount of products sold and farm inputs purchased (in kg or tons) during one year, as well as the acreage of nitrogen fixing crops.

The various items that are included in the calculation are presented on the following pages.



Farmgate nutrient balance

The horizontal arrows indicate the farm's nutrient trade (nutrients purchased and sold). Internal nutrient turnover, leaching and evporation are not included in the farm's net nutrient balance.

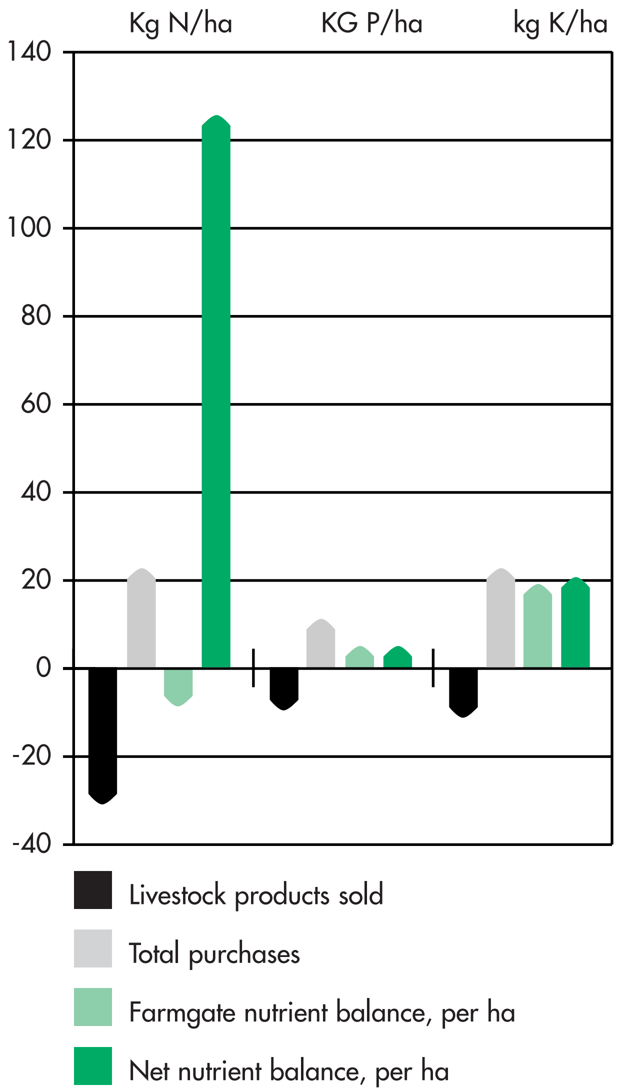
When is it necessary to calculate a farm's nutrient balance?

It is especially important to determine a farm's nutrient balance when the farm undergoes major changes. For example, when converting from conventional to organic farming methods, when giving up or building up livestock, or when considering to buy or sell large quantities of livestock manure, straw or other products.

There are two reasons for (normally) only calculating nutrient balances for N, P and K. First, these are nutrients that are used in large amounts, and thus, one of these is often a yield-limiting factor. Second, P and K are highly comparable to other nutrients. Their chemical and physical properties are extremely different, but each of the two, in their own right, resemble the remaining nutrients quite a bit.

Usually, one doesn't calculate a farm's "complete" nutrient balance. Such items as nitrogen evaporation and N and K leaching vary a lot and are difficult to predict. Therefore, the calculations are generally limited to 'farm-gate' nutrient balances. Nevertheless, one has to take evaporation and leaching into consideration when assessing the results.

A net nutrient balance is comparable to a profit budget. It can be used to discuss how to allocate any surplus (cash budget), or how to finance possible losses.



Nutrient surplus on an organic dairy farm

Securing the nutrient supply is easiest on dairy farms. In this example, the stocking rate is 1.06 AU/ha, and straw is purchased as litter (deep litter barn with slatted floor area) and to cover 5 % of the feed requirement. The farm sells milk, some live cows, young bull calves and some heifers. (More farm data can be found in the chapter »Crop Rotation«.)

Purchased farm inputs

Seed stock, etc.

Purchased seed stock is hardly visible in a nutrient balance. However purchased seed potatoes and similar inputs do have a certain effect.

Livestock

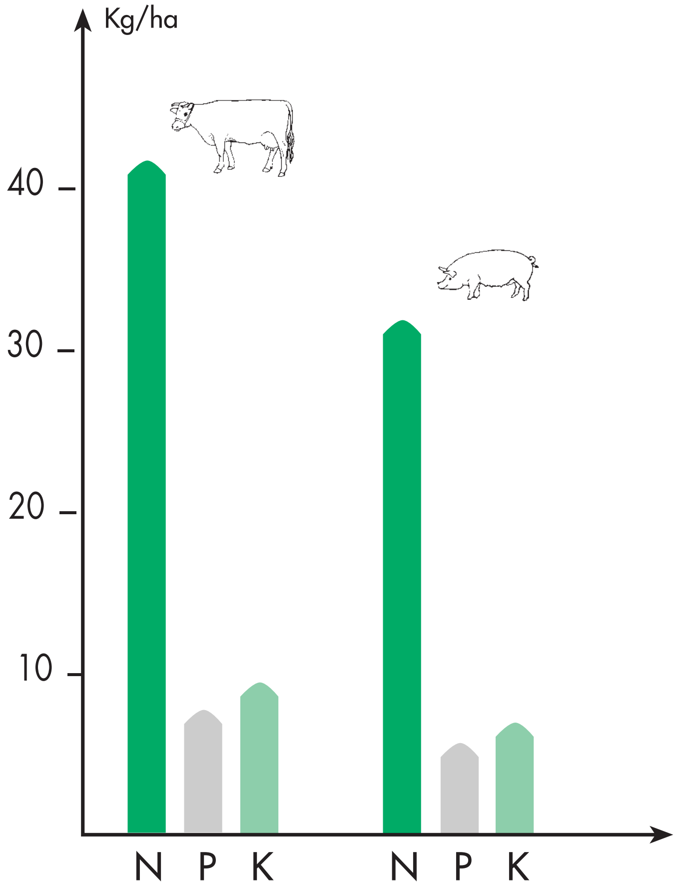
Purchased livestock usually don't affect a nutrient balance very much. There are exceptions, e.g., when buying weaner pigs or calves for fattening.

Feedstuffs

Most organic livestock farmers purchase some feed. One reason may be that they do not have enough land to ensure feed self-sufficiency, another could be that the crops that can be grown on the farm aren't good enough when it comes to optimising feeding plans.

For example, the amino acid composition in pig and chicken feed can be insufficient without purchased feed. Feed rations for dairy cows often lack fat.

Purchased feedstuffs often represent a major item in a nutrient balance.



Amount of purchased nutrients in feed on a dairy and a pig farm

The figures are based on a stocking density of 1.2 AU/ha and a feed self-sufficiency rate of 85 % for cattle and 75 % for pigs.

Minerals

Phosphorus is usually the major mineral input. Even a daily consumption of only about 100 g of minerals per animal results in an annual import of 5-6 kg P/ha.

Straw

Purchasing straw as bedding or feed represents a substantial input of N and K.

First of all, straw has a high content of N and K. This applies especially to conventional straw, where luxury consumption of N and K is deposited in the straw.
Second, organic livestock farms generally have a greater need for bedding material. Regulations require all animals to have access to bedded stalls, and deep litter houses are widespread.
Third, organic livestock farms rarely grow enough grain to ensure a sufficient supply of straw. Thus, purchased straw on a livestock farm with a deep litter arrangement can easily result in annual inputs of up to 15 kg N and 30 kg K per ha.

Fertilizers

The amount of fertilizers purchased by organic farms varies considerably.

The purchase of farmyard manure is the most common practice. It is also a good fertilizer, since it contains many different micronutrients. However, other organic fertilizers can also be used. Inorganic fertilizers include substances found in nature, such as rock powder and rock phosphate.

The regulations for organic production specifically define which products an organic farmer can buy. The regulations also define the products' sources and amounts that can be used.

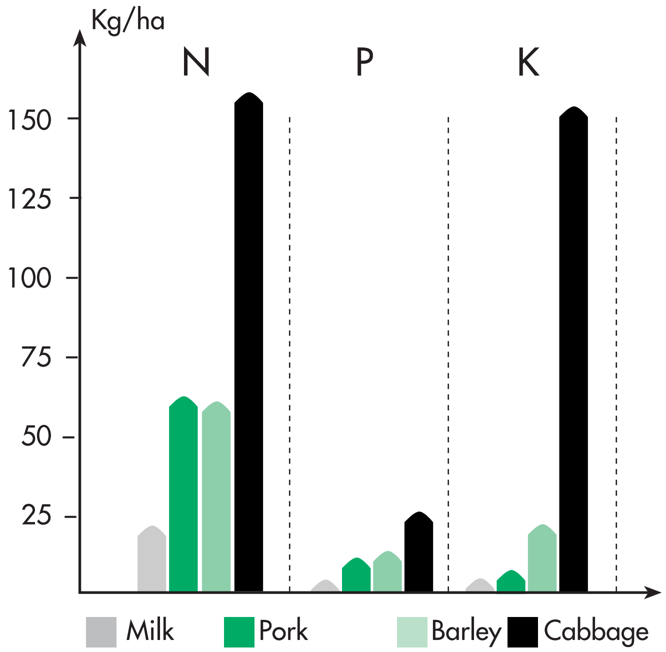
A large share of the nutrients in farm products end up in household wastes or sewage sludge. These nutrients should naturally be recycled to the land as fertilizers. However, this is only done to a limited extent, since one is concerned about the waste's contents of heavy metals, pharmaceutical residues and numerous other chemical substances.

	N	P	K	S	Ca	Mg	Mn
Industry							
Potato juice (P)	1.8	0.3	4.9	0.2		0.2	
Vinasse (sugar beet pulp) (DM)	5	0	210	160	100	0.2	
Vinasse, liquid (P)	3,5	0	8				
Meat meal (P)	7-10	1.5-2.5					
Bone meal (P)	1-4.5	8-12	0.2		8		
Straw ashes (DM)	1	9-15	100-150		20-70	1-10	0.1-0.4
Urban waste (P)							
Sewage sludge	3.5	2.0	0.5				
Composted household waste	3-5	0.7-1.2	1.2-2				
Maritime products							
Seaweed (P)	3	0.5	7		8	8	4
Seaweed/kelp meal (DM)	30	4	2		500	30	1.01
Rock sources (P)							
Rock powder, granite		0.7	20-50		0.5-1.2		
Rock powder, basalt		4	5-25		140-200	10-60	1
Agricultural lime					700-800		
Dolomitic lime					900	100	
Rock phosphate		138			500	30	1.002

Nutrient contents in various fertilizers
Nutrient contents expressed as kg nutrient per ton dry matter (DM) or as kg nutrient per ton raw product (P). Please observe that certain products are not permitted for use in organic farming. Make sure to check the current regulations.

Farm outputs

It makes a big difference if a farm mainly sells livestock or plant products. The figure on the opposite page shows that much less nutrients are exported per ha in milk and meat products than in plant products, e.g., barley or cabbage. The reason is that most of the nutrients in livestock feed remain and are re-used on the farm as manure.



Amount of nutrients exported in sales of livestock and plant products
The figures are based on a stocking density of 1.2 AU/ha and average yields in Denmark.

In other words, you can already now see that organic crop farms face a substantial challenge. Farms selling vegetables or fodder crops have even bigger problems than organic cereal farms or seed growers. Per hectare, such farms export a greater biomass, and thus more nutrients, than farms that merely sell cereal grains, oilseeds, pulse crops or grass seeds.

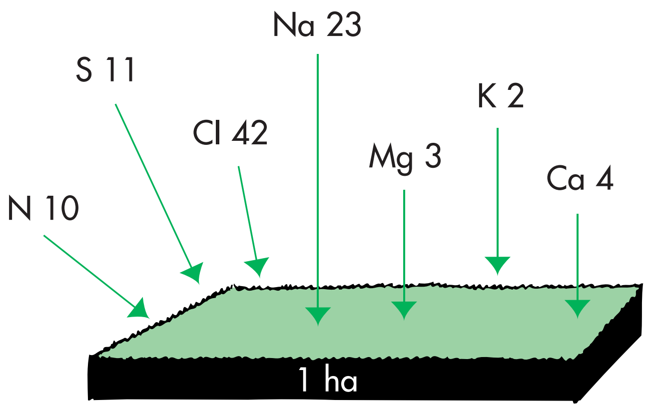
In crop husbandry, the export of nutrients can be reduced in several ways:

- Grow crops that minimise the export of nutrients. This applies mainly to seed and grain crops.
- Introduce some form of livestock husbandry.
- Process plant products on the farm. In this way, rejects and wastes remain on the farm.
- Introduce whole-season green manure in the crop rotation. This reduces the acreage from which nutrients are sold. (A field of whole-season green manure has numerous other effects, which will be described later).

Inputs from the environment

Atmospheric deposits

Atmospheric deposits contribute to steady input of nutrients to the soil. Many of these are dissolved or suspended in rain and snow. The amount of some of these nutrients is presented in the figure below. The majority of these nutrients originate as pollution from industry, power plants, domestic heating and transportation.



Nutrient input from atmospheric deposits (approximate figures as kg/ha/year) in Denmark

However, some nutrients evaporate from the soil, plant residues and animal manure. This mainly applies to nitrogen.

Biological nitrogen fixation

Nitrogen fixation by legumes is by far the most important source of nitrogen for an organic farm. Organic farmers thus have to make sure that their crop rotations include enough leguminous plants.

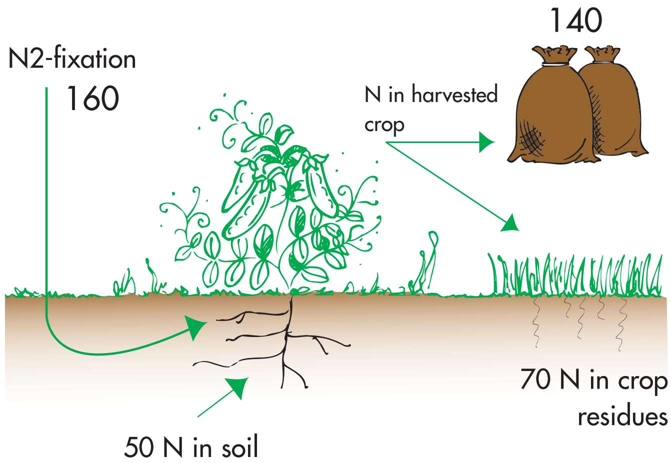
Many different crops can be grown to increase a farm's nitrogen supply through N-fixation:

- Grass-clover leys or lucerne
- Whole-crop silage, e.g., peas and field beans, or mixtures of barley/peas or winter wheat/winter vetch
- Pulse crops or barley/peas to maturity
- Undersown green manure with clover, especially winter-hardy clover species
- Whole-season leguminous green manure ("fallow")

The table on page 31 shows how much nitrogen various crops can fix per year. However, many different factors affect nitrogen fixation (see figure on page 32), and for the same crop there can be considerable variations between years or fields.

It is important to note that the more nitrogen is available on a farm, the less atmospheric nitrogen will be fixed by legumes. The figures for annual nitrogen fixation are thus difficult to estimate and somewhat unreliable.

One also has to be aware of how much nitrogen leaves the farm in sold products.
On organic crop-growing farms, a natural choice is to grow and sell pulse crops. However, this does not result in any significant net input of nitrogen to the farm. The amount of nitrogen fixed from the atmosphere is roughly equivalent to the amount of nitrogen in the pulse crop, see figure below. The remaining nitrogen, now bound in the crop residues, may possibly be easier available to following crops than before (as soil N), but the total amount has hardly increased.



Nitrogen balance in a pea field, kg N/ha/year
The pulse crop removes nearly the same amount of nitrogen as is fixed from the atmosphere. The yield is 40 hkg/ha with a nitrogen content of about 3.5 %.

The same is valid when selling whole crops, such as lucerne, whole-crop or grass-clover silage. For these crops, there is also a significant export of potassium and other nutrients.

Nutrient balance assessment

In the table on the next page, figures for net N-input on different farm and soil types are presented. The figures are based on model estimates, and the table also includes calculated figures for nitrogen leaching. The table can be used to make comparisons with your own farm.

Calculated net N-input does not include N-losses due to evaporation and leaching. However, one cannot operate a farm without a certain extent of such losses. These must be individually estimated.

Potassium and phosphorus leaching

Nutrient leaching is closely linked to the amount of precipitation in the period without growing crops. For this reason, leaching varies a lot from year to year. In addition, different factors affect the risk of leaching for each specific nutrient.

Phosphorus
Earlier, it was assumed that leaching of phosphorus was insignificant, less than 0.5 kg/ha/year. This assumption was based on the observation that all P-containing compounds were poorly soluble in water.

However, phosphorus can be lost ,e.g., if soil particles and phosphorus compounds are leached through the soil profile via cracks and macropores, or via surface runoff to watercourses. This is termed as leaching or runoff of particulate phosphorus.

Recent studies on Danish farmland have shown that the soil has become so saturated with phosphorus that there now definitely is a high risk of P-leaching. In some areas, the leaching of phosphorus from farmland to streams, lakes and fjords is becoming a problem. Earlier, P-rich urban wastewater was the main problem, but in the past few decades this has improved because of more efficient wastewater treatment systems.

Potassium
Rather large amounts of potassium can be lost due to leaching. Losses increase with decreasing contents of clay and humus in the soil, both of which bind potassium. On loam and clay soils, K-losses can be regarded as insignificant.
Like potassium, other positive ions (e.g., Na^+, Ca^{++}, Mg^+ and NH_4^+) are also easily leached on sandy soils. However, the K^+ cation has the weakest binding to the soil colloids

			AU/ha 1)	Total N input	N 2) Atmos-phere	N in farmyard manure	N in mineral fertilizer	N in harves-ted crops	Net N supply	N 3) leaching
Crop farms										
	Clay soils	conv.:		146	22	4	120	121	25	32
		org.	(0.45)	116	69	47	0	56	60	19 (29)
	Sandy soils	conv.:		212	31	96	85	105	107	90
		org.	(0.45)	104	61	43	0	44	60	36 (46)
Pig farms										
	Clay soils	conv.:	0.7	195	23	65	107	125	70	47
		conv.:	1.5	210	21	115	75	114	96	38
		conv.:	2.7	256	34	166	56	94	162	57
		org.	0.8 (1.4)	208	67	141	0	87	121	30 (47)
	Sandy soils	conv.:	1.3	210	32	102	76	109	111	97
		conv.:	1.8	262	30	173	59	99	163	138
		org.	0.6 (1.4)	218	73	144	0	68	146	63 (98)
Cattle farms										
	Clay soil	conv.:	1.4	241	25	130	87	150	91	48
		org.	1.0	216	89	126	0	126	90	28 (49)
	Sandy soils	conv.:	0.6	223	26	65	131	118	105	89
		conv.:	1.5	284	49	146	89	156	128	90
		conv.:	2.4	363	37	200	126	168	195	119
		org.	1.0	215	91	124	0	126	91	65 (104)

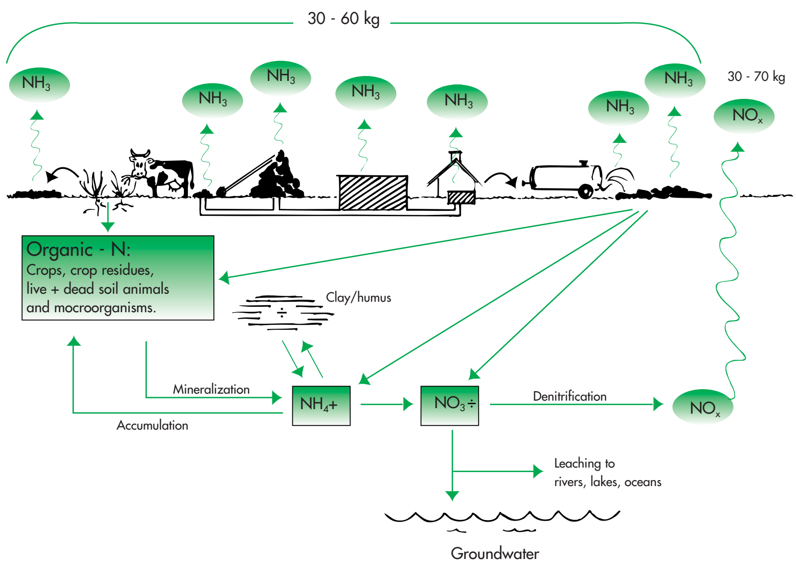
1) Figures in parentheses include imported animal manure
2) Nitrogen fixation plus atmospheric deposits (estimated at 20 kg N/ha/year)
3) Figures in parentheses are calculated N leaching from organic farms without catch crops

Nitrogen balance and estimated leaching from conventional and organic farms in Denmark (as kg N/ha/year)
These model calculations include currently available measurements and know-how regarding nitrogen turnover. Note that the table does not include the evaporation of ammonia and nitrogen oxides (FØJO report nr. 2, 1998).

Leaching and evaporation of nitrogen

Nitrogen is especially hard to manage, since it occurs in many different forms, most of which are unstable.

Total N-losses from a farm are highly variable and difficult to predict. Nitrogen denitrification and leaching depend greatly on the amount of precipitation and temperatures in the winter, as well as on the soil type. However, through sensible farm management a farmer has a lot of influence on the extent of these losses: how is the soil structure, is the soil tilled at the right time, what form of manure treatment, what kind of crops/catch crops are grown, etc.



Sources of nitrogen losses
Typical figures for Danish farms, shown as kg N/ha/year. Nitrogen is best preserved when is is bound in organic matter: living plants, crop residues, soil animals, microorganisms and the solid manure fraction.

The following estimated nitrogen losses can thus be included in the farm nutrient balance presented on page 49 at the left.

Estimated N losses in the case study presented on page 49

	Intermediate calculation,	N loss kg/ha/year
Leaching of NO_3-N	*1/2 of 90 kg N*	*45*
Evaporation of NH_3-N	*1/4 of 80 (AU x 100 kg N): 80 ha*	*20*
Evaporation of NOx-N		*10*
Total		*75*

Gaseous nitrogen compounds

The gaseous nitrogen compounds are highly volatile. These are:

- Ammonia (NH_3)
- Nitrogen oxides (collectively called NO_X)
- Atmospheric nitrogen (N_2)

Ammonia evaporates mainly from animal manure: while still in the barn, during storage and spreading. In the soil, ammonia is rapidly transformed to ammonium (NH_4^+). Having a positive charge, it is bound to the soil colloids. Ammonium is in turn rapidly transformed by soil bacteria to nitrate (NO_3^-).

Because of its negative charge, nitrate cannot bind to the soil colloids. Nitrate does not react with other chemical substances, e.g., like phosphorus. Furthermore, nitrate is highly soluble in water. It is therefore very prone to leaching if not immediately absorbed by a growing crop.

If the soil is waterlogged and there is little oxygen, anaerobic bacteria transform nitrates to different nitrogen oxides (NO_3^- to NO_X). This reaction is called denitrification. Nitrogen oxides are volatile, gaseous compounds. Denitrification usually occurs during winter, when soils can be waterlogged. Anaerobic soil conditions are most common in soils with poor soil structure and in clay soils.

N, P and K surplus

After having estimated nitrogen and potassium losses, there still may be a nutrient surplus. This is often the case on livestock farms with stocking rates of above 0.5-0.7 animal units per ha. In the example presented here, the surplus of nitrogen still amounts to about 50 kg N/ha.
The obvious question is therewith: what happens to this surplus? What are the consequences for the farm? Is such a surplus justifiable from an ecological standpoint?

Nitrogen

A surplus of nitrogen can imply:

- Yields can be increased. Alternatively, the amount of purchased feed can be reduced.
- Symbiotic nitrogen fixation per ha decreases when the content of soil-N increases (as a result of sustained N-surplus).
- An increase of the soil's nitrogen pool. Nitrogen can be accumulated in soil organic matter. However, leaching of N from the soil N-reservoir may increase as the amount of soil organic matter increases.
- The actual N-losses are greater than the estimated figures.

Naturally, increasing yields are easy to detect. But otherwise, it is hard to determine which of the mentioned effects a N-surplus leads to. It can possibly result in a combination of all of the above-mentioned consequences.
The most important thing is to understand which effects there *may* be, and to evaluate if they are

acceptable. Finally, one has to consider how to possibly reduce a nitrogen surplus. If you don't efficiently utilise the available nitrogen, you actually waste a part of your efforts and costs. At the same time, unnecessary nitrogen losses are an environmental stress.

Phosphorus

To start with, a surplus of phosphorus will be strongly bound in the soil or incorporated in the soil's organic matter. This is a positive development, since it increases the soil's phosphorus-pool, from which P later can be released.

However, a sustained P-surplus may lead to the continued growth of the soil's phosphorus reservoir. This has been the case in Denmark during the past 30-40 years. An undesirable result of this development may be that P-losses from arable land to watercourses will gradually increase.

Potassium

A surplus of potassium can easily be leached. However, it is not known that potassium has any harmful effects on the environment.

Some of the surplus potassium can be incorporated in the soil's organic matter. In clay soils, some excess potassium can also be bound to the clay colloids.

N, P and K deficiency

Deficiencies of N, P or K can imply:

- Lower yields than expected.
- Soil nutrient resources are consumed (by mineralisation of soil particles).

Is it possible to consume the soil's nutrient resources? For how long?

Is it desirable to purchase additional nutrients? If so, is this permitted e.g., in relation to organic regulations, and are they available?

In any case, you should thoroughly consider how to reduce losses if your calculations indicate a nutrient deficiency. This will be further discussed later on in this chapter.

Phosphorus and potassium

The soil's reservoir of these (and other) nutrients can be significant, especially in clay soils. In the plough zone alone, there can as much as 3 tons P/ha and 90 tons K/ha. Additionally, there are enormous reserves deeper in the soil. Given that the release of nutrients from mineral weathering occurs at a sufficient rate, it would be possible to counteract an annual net deficiency of 5-10 kg P/ha or 50 kg K/ha on a clay soil.

On sandy soils, it's a different story. The natural nutrient reserves are much smaller and losses due to leaching can be twice as high. There should thus not be a P or K deficiency on such soils. Some leaching of potassium is unavoidable, but this can be compensated by mineralisation, which also occurs in sandy soils.

Nitrogen

The soil's nitrogen reserves are almost exclusively incorporated in the organic matter.

It originates from nitrogen fixation or organic fertilizers that have applied in previous years. If the content of soil organic matter is high, one can naturally choose to consume these reserves for a while. On Danish cattle farms, the soil nitrogen pool has increased by about 25-50 kg N/ha per year.

It is nonetheless important to maintain a constant nitrogen pool, i.e., avoiding N deficiency after making an allowance for leaching and evaporation. Otherwise, the result will be lower yields.

Nutrient surplus *- no guarantee!*

Even if you have a comfortable nutrient surplus at the whole-farm level, there is no guarantee that all crops are receiving enough nutrients at the right time.

The next challenge

The calculation of the net nutrient input gives you an indication of the nutrient status of the entire farm. Even though the farm-level balance may be positive, there can nevertheless be a nutrient surplus on one field, and a deficiency on another.

The next challenge is thus to make sure that there are enough nutrients for each crop. In other words, efficiently utilising the farm's nutrient resources.