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7 PLANT NUTRITION AND FERTILIZATION

7.1 THEORY AND SPECIFICS OF PLANT NUTRITION IN ORGANIC AGRICULTURE

Plant nutrition is a physiological process closely linked to photosynthesis and the natural cycle of materials. Apart from plants and some lower organisms, for example cyanobacteria, the whole chain of organisms at various trophic levels including humans and soil biota, organisms that revitalise and enrich the soil, is dependent on **organic nutrition**, the primary source of this being plants.

Reasons why organic agriculture renounces the use of synthetically produced nitrogen fertilizers:

- so as not to create an artificial imbalance in soil solution and avoid plants receiving biased nutrition (over-fertilization),
- so as not to attract pests, drawn by the high nitrogen content of plant tissue,
- so as not to restrict (destroy) soil life,
- so as not to waste energy in the production of nitrogen fertilizers,
- so that organic farmers have to make an effort to efficiently manage nitrogen (growing Viciaceae plants and correctly handling organic matter) thus bringing further benefits to the overall fertility of the soil.

Plants draw **nitrogen** from the ground, which it enters from the air, mainly through biological processes. Airborne nitrogen can only be assimilated by certain micro-organisms – bacteria living freely or symbiotically in the soil, actinomycetes and cyanobacteria. Symbiotic rhizogenic bacteria and actinomycetes obtain organic nutrition from their host plants. Free-living fixers of airborne nitrogen, except autotrophic cyanobacteria, need organic substrate for their nutrition – humus, again primarily a product of plant photosynthesis. The symbiosis of Viciaceae plants (legumes) and nodule bacteria is of fundamental importance to agriculture and, especially to organic agriculture. Clovers must be included in the crop rotation to such an extent as to supply the soil with sufficient nitrogen for subsequent crops (including fodder and commercial crops). Fodder crops at least partly return nitrogen to the soil via farmyard manure. Depending on type and environmental conditions, leguminous plants fix from a few dozen kg of nitrogen (legumes such as peas, field-pea etc.) up to several hundred kg of nitrogen per hectare (clovers, alfalfa).

Organic agriculture forbids the use of easily soluble, synthetic nitrogen fertilizers, i.e. saltpetre, including Chile saltpetre, even though it is of natural origin, and ammonium sulphate and urea, which is an organic compound, but is synthetically mass-produced for the purpose of fertilization.

Nitrogen is also present in **humus** which, to a greater or lesser extent, takes part in the exchange of nutrients, acting as their accessible store. Over the course of many years nutritional humus largely breaks down, mineralises and becomes nutrients which are again accessible to plants. It partly contributes to the formation of permanent humus, whose function in plant nutrition is mainly to regulate the soil's handling of moisture and nutrients. Humus has huge capacity for sorption and retention of nutrients. Along with clay minerals and other soil components it forms the organo-mineral sorption complex. The mobilisation of nitrogen in the soil is increased by aeration (ploughing, tilling), adequate irrigation and organic fertilization with a close ratio of carbon to nitrogen (C:N). It is known as the "Priming Effect" where the added nitrogen provokes the mineralizing activity of soil biota for a certain period of time. Thus mobilized, the "extra nitrogen" is available to plants. It is, however, to the temporary detriment of nutritional humus and under certain conditions this nitrogen is in danger of being washed out or lost through denitrification.

Unlike the natural ecosystem with its rich and varied biodiversity, productive agro-ecosystems generally deprive the soil of humus. Humus is broken down most in root crops and other wide-spaced crops. In contrast, perennial fodder crops (clover/grass and alfalfa/grass mixes) allow humus to re-accumulate in the soil. This too is a reason for needing sufficiently to cultivate these crops if we wish to ensure the long-term fertility of the soil.

Apart from nitrogen, all **other nutrients** – calcium, magnesium, phosphorus etc. originate in minerals and rock in the soil-forming substrate from which the soil originated and is continually developing. These biogenic elements gradually break away from the firm chemical structure of an almost insoluble compound into soluble form and enter the soil solution as free cations and anions. These are then retained in the soil as a supply of plant-friendly nutrients with various sorption mechanisms and continuous recycling. Various forms of co-existence between plants and bacteria, actinomycetes and fungus are extremely significant for the supply of phosphorus and other nutrients. From its roots a plant secretes organic material and dead cells into the soil, providing nutrition for rhizospheric micro-organisms.

On the surface of the roots and in their immediate vicinity, there is several times more activity of soil life than in more distant zones.

Many rhizospheric micro-organisms have more effective enzymes and other substances with which they are able to release nutrients from less accessible organic and mineral forms for themselves and host plants. Some types of fungus live in very close symbiosis with plants, so called endomycorrhiza. Part of the fungus hyphae grow inside the plant roots where they obtain organic nutrition. Outside the roots the hyphae grow into a volume of soil that the plant alone would not be able to utilize. **Mycorrhiza** improves the intake of nutrients and the overall vitality and resilience of the plant. It has been repeatedly proven that mycorrhiza and many other forms of mutually beneficial co-existence between plants and micro-organisms are more efficient in soil that is managed organically, without the use of synthetic pesticides and fast acting mineral fertilizers.

In organic agriculture special emphasis is put on maintaining and improving the fertility of the soil, which is inconceivable without organic fertilization, i.e. nourishment for soil biota. A fundamental principle of OA is the effort to maximise the recycling of nutrients, i.e. their return to the natural cycle, so that the current generation does not over-exploit non-renewable resources or pollute the environment.

Plant nutrition is a combination of physiological processes whereas fertilization, where fertilizer may be applied in various forms, is one of the agro-technical measures (soil cultivation, irrigation, crop rotation etc.) with which we can contribute to the optimisation of plant nutrition. Fertilization should maintain and improve the fertility of the soil, provide organic nutrition for soil biota, return nutrients to the natural cycle (organic fertilizer produced by the farm itself) and additionally ensure the replenishment of nutrients removed from the soil through farm production. With organic fertilization we enhance the biological activity of the soil, which is the basis of its fertility. Biological activity maintains nutrients in accessible form and helps plants to obtain nutrients even from less accessible organic compounds and minerals. In biologically active soil, plants are generally more tolerant; they are more capable of resisting invasion by disease and pests. Proper care of organic fertilizer, its use on organically managed farms and the resulting balance of nutrients, are described in the following sub-chapters.

Production of farmyard fertilizer (according to Duchoň and other authors):

Type of farmyard fertilizer	Kg/day	Ton/year
Cow dung – dairy cattle	32–38	12–14
Cow dung - heifers	16–20	6–8
Pig dung (100 kg)	5–5.5	1.8–2
Sheep dung (45 kg)	2–2.5	0.8–1.0
Slurry – various animals, calculated for 1 LU	50–70	18–35
Urea (cattle)	10–15	4–5.5

Composition of farmyard fertilizers in % (according to Škarda 1982)

Type of fertilizer	Dry matter	Organic matter	N	P	K
Medium quality manure	22	17	0.48	0.11	0.51
Cattle slurry (before storage)	7.7	5.7	0.30	0.06	0.24
Pig slurry	4.4	4.8	0.49	0.11	0.17
Urea	0.6–4.8		0.05 –0.91	trace	0.12 –1.41

Different conceptions of plant nutrition in organic and conventional agriculture:

- Cultivated plants are supplied with nutrients indirectly, through the soil-plant system, in which a key role is played by soil life responsible for the processes of decomposition and transformation.
- The conventional teaching, that it is necessary to replace nutrients in the soil that plants take out, does not apply in organic farming. This principle did not consider the fact that the soil is a living, productive ecosystem.
- Soil micro-organisms can mobilise nutrients from mineral components of soil, from the air (nitrogen) and from organic residue and, make these accessible to plants.

7. 2 FARMYARD FERTILIZERS AND THEIR MANAGEMENT

Correct use of organic fertilizers and crop residues is very important in OA. Farmyard fertilizers from animals kept on the farm complete the cycle of elements, returning them to the soil for the further use of plants in the system. Organic fertilizers influence the physical and chemical properties of the soil and are an important source of energy and nutrition for the soil sub-ecosystem. This is especially the case in OA where animals graze and are allowed to move freely. It is very important to keep to an optimum ratio of animals to land and to carefully manage the consequential fertilisation.

7.2.1 Manure

Manure is the most common organic fertilizer used in agriculture. It is possible to calculate the production of dung in farm operations according to the following equation:

Dung = the coefficient for calculation of D (dry fodder/2 + dry bedding) where (the coefficient is determined by the dry matter, ranging from 3 to 5). For fresh cattle dung an approximate coefficient of 4.5 can be used.

Production of mature manure (M) can be calculated according to the following equation:

M = the coefficient for calculation of M (dry matter as in hot processing, but material is divided by 2 + dry bedding), where the coefficient equals 2.9 if loss is 30 % or 2.1 if loss is 50 %.

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Guideline daily requirement of straw for individual categories of farm animal (Škarda 1982):

Category	Daily requirement of straw in kg per LU
Cattle – medium stall	2–3
Cattle – long stall	3–5
Cattle – deep bedding	5–10
Pigs - penned	2–5
Horses	3–4
Sheep – deep bedding	3–5
Poultry	3

Possible methods of processing and storing dung:

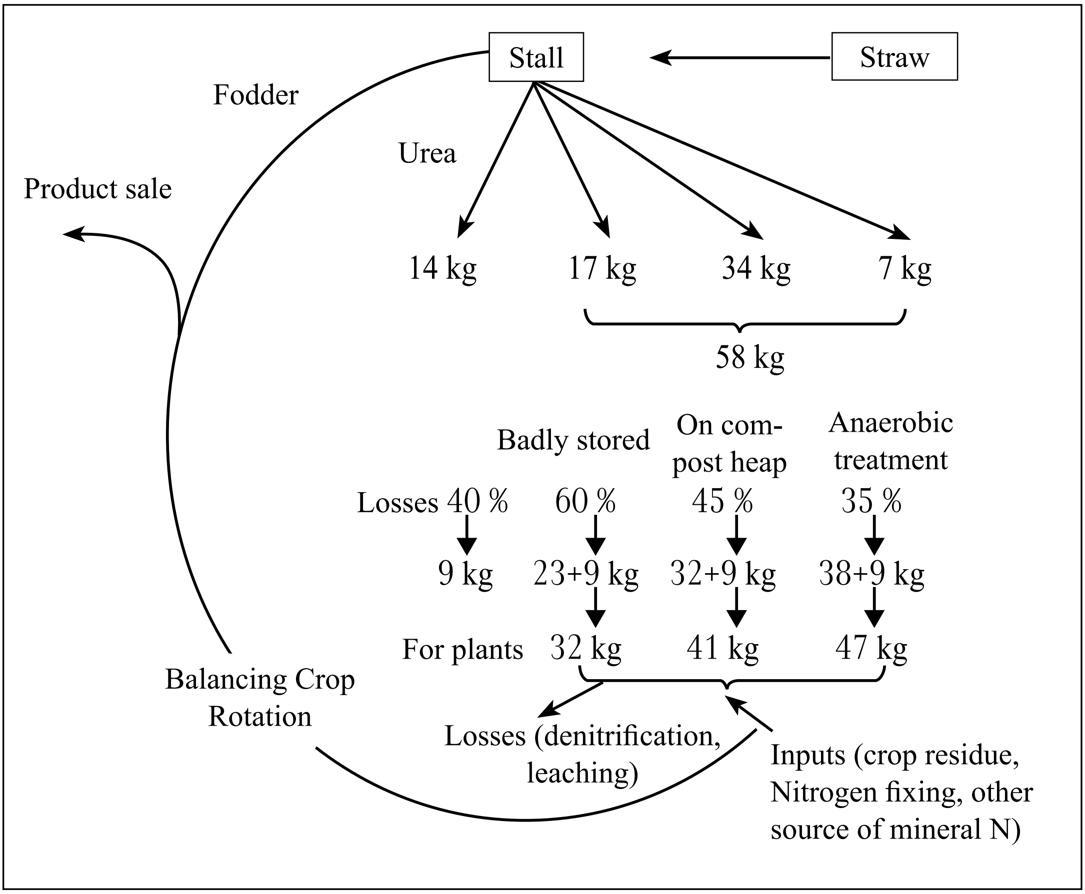
1. Cold – when the dung is stored in blocks which are immediately compressed in an attempt to restrict decomposition of the organic matter. The storage temperature remains up to 30 °C. This storage also reduces the loss of ammonia and the anaerobic conditions eliminate the germination of seeds and pathogenic organisms. Manure from this system may cause losses if the material produced through storage with restricted air flow has a negative influence on root growth and microbiological processes in the soil. Matured manure in anaerobic conditions contains a higher amount of ammonia nitrogen (around 40 %) than compost, which has about 5 % of this form and roughly the same amount in the form of nitrates and a significant amount of organically bound nitrogen

2. Hot Fermentation (Heap Composting), using a combination of controlled aerobic and anaerobic processes. In the aerobic phase the temperature rises to about 50 °C and, at this point (after 2–4 days), the material is sealed when another layer of fresh dung is put on top. The rise in temperature has a self-sterilising effect on the dung. The proportion of fixed nitrogen and quantity of potassium suitable for plants is higher than in dung stored cold.

3. Anaerobic Fermentation and production of biogas (Czech patent) – the initial storage phase is similar to the hot method, but the material is stored in special fermentation units. After the material warms up to 50 °C it is not covered with more dung, but the fermentation unit is hermetically sealed. Then the biogas is collected. It is mostly methane and carbon dioxide. It can be used on the farm e.g. for heating buildings or providing hot water. This method of fermentation reduces the loss of organic material and nutrients and also destroys the germinative capability of seeds and germs.

4. Sheet Composting – during which cold aerobic decomposition takes place, is intended to simulate conditions in the natural ecosystem, where the organic matter remains on the surface and isn't worked into the ground as it is in the agro-ecosystem. However, with the addition of stabilized composted material to the soil there is less disturbance of the balance of the soil. As heap composting (2 above) is implemented and preferred in many OA systems, more attention will be given to it in another chapter.

In storage of dung and manure there are certain losses. With incorrect handling the loss of nitrogen can be as high as 60 % (see following diagram according to Šarapatka, 1992)



The question of using manure and compost is much discussed in organic farming. The effect of using manure and compost on yield and soil characteristics is given in results of research by Sauerland (first 3 columns) and Otto (last 3 columns) (publ. Lampkin, 1990).

	Without manure	Manure	Compost	Without manure	Manure	Compost
Yield (%)	100	146	163	100	116	118
Organic matter (%)	2.70	2.89	3.13	1.48	1.56	1.62
Intake of phosphorus (mg/kg)	28	44	51	34	48	60
Intake of potassium (mg/kg)	37	70	91	260	326	356

Further losses and reduced effect of manure may occur later during application, if it is not quickly worked into the ground. If this is done one day after application, the effectiveness of the manure is reduced by about 10 %, after 4 days it is down by 15 %. Loss of nitrogen and fertilization value are shown in the following table:

Time between application and incorporation	Loss of N in % spring application (Swiss research)	Loss of fertilizing value in % (earlier Czech research)
6 hours	19	16
1 day	22	21
4 days	29	36

From the data it is evident that this is quite a complicated problem, influenced by a number of factors. It is not easy to find a simple formula for handling manure, it depends on specific conditions. The following table may assist in making decisions:

	Option of composted manure	Option of fresh manure
Aim	long-term gain	Short-term gain
	Soil fertility	yield
Specific factors		
Amount of manure	excess	deficit
Soil type	Light soils	Heavy soils
Crop rotation with legumes	Positive Nitrogen balance	Negative Nitrogen balance
Crop type according to:		
Vegetation period	Long (grasses)	Short (spring field crops)
Nutrition requirement	Low (cereals)	High (potato)
Nitrate risk	High (lettuce)	Low (cereals)

7.2.2 Urea

Urea is the fermented urine of farm animals diluted to an unspecific extent and depleted of nutrients which are bound in the bedding material or are lost in storage or application. This loss of individual nutrients can be as much as 50 %. Depending on the type of stable and the water consumption, the yearly production of urea can be 4–5 m^3 per livestock unit (LU). Storage capacity must, therefore, be adequate for the system implemented. There can even be a loss of nutrients from these storage facilities. For instance, loss of nitrogen from an open storage pit can exceed 40 %, or 23 % from a pit with a floating wooden cover.

The fertilization value of urea depends on the method of production, treatment and application. Insufficient operational care and heavy dilution with process water or rainwater has great effect on its quality. The nutrient content of this type of fertilizer therefore varies greatly. Nitrogen is between 0.05–0.7 %, phosphorus from a trace amount to 0.01 % and potassium from 0.1–1.3 %. In urea about 90 % of nitrogen content is in easily soluble form with ammonia nitrogen in greatest proportion. With a load of 1 LU per hectare we can expect to have 10 kg N, 0.5kg P and up to 20 kg K in urea for each hectare. From this composition it is evident that, in terms of chemicals, urea is nitrogen-potassium fertilizer.

Besides direct use for fertilization, urea can also be used in composting and in treating manure with a high straw content.

7.2.3 Slurry

The production of slurry, as various thick mixtures of excrement, urine and other materials diluted with water, was previously associated with highland regions with predominant cultivation of fodder crops and a lack of roughage.

Slurry is an organic fertilizer which, according to research on selected beef-cattle farms, contains 7.7 % solids, 5.7 % organic matter, 0.3 % nitrogen, 0,06 % phosphorus and 0.24 % potassium. However, because of excess quantities of process water, slurry does not reach these levels on many farms and its solid content often falls below 2 %. A first step in an agricultural operation is therefore to achieve the necessary quality in this farmyard fertilizer.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Storage facilities for slurry must be of appropriate capacity

Keeping animals in stalls with grid floors is forbidden in organic farming. If, however, slurry is produced on an organic farm it is recommended that it be aerated in storage. Research has proven the effectiveness of aeration in reducing smell and in reducing the disturbance to soil life after its application. This method also restricts the survival of weed seeds and pathogens in slurry and increases the value of slurry as a fertilizer. Aeration reduces the loss of nitrogen during application, as the originally high content of ammonia nitrogen is converted to the form of bacterial protein. The quality of slurry can also be increased by the use of bentonite and rock flour.

7.3 COMPOSTS AND COMPOSTING

Well-considered and careful handling of nutrients in the ecological system is the basis for success in organic farming.


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The decomposition processes of organic matter in soil, with respect to the release of nutrients, are described in the chapter on soil and can be specifically applied in the composting process.

Breakdown of organic matter – basic principles:

- Anaerobic – maturation of dung, silage, biochemical change in substance occurs in a lack of oxygen
- Aerobic – mineralization in the presence of oxygen has two phases: 1 – carbonization – oxidation of carbon components, 2 – nitrification with oxidation of nitrogen material.

Composting is the original natural process of decomposition of organic matter during which, in aerobic conditions, there is a breakdown of organic matter.

In composting we identify four phases. In the first phase the material begins to warm up and the temperature within the heap can reach 60 °C. The cause of this rise in temperature is the mass multiplication of micro-organisms breaking down the easily decomposable materials. In this phase germs and seeds of weeds are eliminated. In the second phase the breakdown of less-decomposable material continues. There then follows a material transformation phase when mineralization also begins. In the final, fourth phase, the action of micro-organisms and chemical reactions produce more complex organic materials of humus character.

Method

Compost is characteristically a mixture of organic materials and soil, activated by beneficial microflora, in which humus-forming processes have taken place or are ongoing. Composting enables organic material and nutrients, both from farm activity and other non-agricultural sources, to be returned to the cycle of materials in nature. They would otherwise be lost from agriculture. Raw materials for composting can comprise all organic farm waste (plant remains – weeds, straw, poppy heads, potato leaves, chaff, feed waste, tree leaves, dry meadow-grass, grass sods etc.) and wood material (sawdust, wood-chips, bark etc.). To this we can add inorganic material (soil, pond mud, ash etc.), substrate with microbial activity (dung, slurry, urea).

Basic conditions for composting:

- Nutrient ratio C:N = 30:1
- optimal moisture
- 10 % proportion of soil
- homogenization of the mass – mixing the raw materials and initiating the composting process.
- maintenance of aerobic conditions in the heap by digging over to maintain the proper composting process.
- in the first week (in proper establishment of conditions – ratio of nutrients and optimal moisture) maintain temperature below 65 °C by aeration - digging over.
- for 21 days from the start of the composting process it is necessary to keep the temperature above 50 °C to sanitize the heap.
- completion of the composting process in 6–8 weeks, it is then recommended to check maturity.

In positioning the compost heap, choose a location which will not endanger ground water or surface water.

<u>Permanent composter</u>

- hard surface sloping down to a drainage pit for rainwater.

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Measuring basic parameters in composting process

The base of the composter must have a 1.5 – 3.0% incline towards the drainage pit.

- heaps should be positioned so as not to retain rainwater – perpendicular to contour.

<u>Field composter</u> – one-off production of compost (on the edge of a field) where the organic matter was produced or near the place where it will be used, in a location where there is no danger of pollution of groundwater. The heap must be positioned on a slope so as not to retain rainwater and along a firm surface, e.g. a path, which will allow the compost to be dug over even in bad weather. A suitable place for a compost heap is under the shade of a tree. In areas with annual rainfall of more than 500 mm, compost should be covered. Nowadays, non-woven materials can be used for this purpose.

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Processes taking place during composting

<u>Monitoring the proper functioning of the composting process</u>

- checking moisture – experienced touch and feel by hand or physical analysis,
- measuring temperature – in the first 10 days it is necessary to measure the temperature every day as the temperature shows how the composting process is developing. For the following 11 days it should be checked every second day and then once a week until the end of the composting process.

Equipment

For a carefully managed composting process, it is necessary to equip the farm with special composting equipment – a compost turner. It can be either a tractor-towed instrument or a self-powered machine. These vary in performance capacity and size of financial investment. Alternative equipment for composting – a loader or spreader cannot replace a turner and the resulting product will be of lower quality.

Using compost

Compost is a stabilized organic fertilizer with a 30–50 % content of organic material, 0.3–1.0 % N, 0.2 % P, 0.8 % K, 2.5–3.5 % Ca + Mg, pH 7.5–8.0.

Applying compost

Compost is applied with a muckspreader. Compost is not only a source of nutrients for plants, but also contains a considerable number of micro-organisms important to the soil environment. Compost should not be ploughed in deeply. It should be applied either as initial fertilization lightly worked into the ground, or as regenerative re-fertilization with harrowing.

Including compost in crop rotation and grassland

The quantity of compost for fertilization depends on the demands of the cultivated crops – see following table. Fertilization with compost minimizes the risk of over-fertilization due to the form of organically-bound nutrients. It can therefore be applied in both spring and autumn.

Crop	Dose (t/ha)	Time of application
Winter wheat	6–8	Spring, after the end of winter weather, work in with tine harrows
Spring rye	4–6	Before preparation for sowing (work in to a maximum depth of 10 cm)
Potato	10–13	During preparation for planting (to the depth of 10 cm)
Permanent grassland	3–5	2 × a year – first dose in spring, second after first mowing or in autumn. Always harrow in after application

7.4 METHODS OF APPLYING FARMYARD FERTILIZER

The method of fertilization can influence the amount of nitrogen lost from farmyard fertilizer in the period between application and working in. The method of applying and working in fertilizer can affect the speed with which it breaks down and the nutrients mineralize. If fast break-down and mineralization of nutrients is required, the fertilizer should be worked in shallow. If a slower decomposition process is required to enrich the soil with more stable forms of organic material, the fertilizer should be worked in deeper (especially fertilizer with a wider ratio of C:N, e.g. straw).

Generally speaking, on lighter soils and in wet conditions, farmyard fertilizer is worked in deeply, while on heavier soils and in drier conditions only shallow.

In OA it is advisable to fertilize with organic fertilizers more often, i.e. intervals of 2–3 years and smaller doses. This rule is easy to keep, in the application of stable manure or compost along with green manuring and fertilizing with straw.

OA legislation allows the use of farmyard fertilizer originating from conventional farms on condition that it does not come from stables without bedding, where animals have no straw litter, or from poultry kept in cages.

Manure

Manure is spread in cool, damp and calm weather in doses shown in the following table. When applying manure to a field of stubble in summer time, the manure should be spread in the late afternoon, if possible, and immediately worked into the ground. The manure soon breaks down and the mineralized nutrients are used either by plants in the following winter crop, or by a green manure crop, thus being “conserved” for the vegetation period of the following year. If neither a winter crop nor green manure crop is to be grown, the manure should be applied in autumn, as a rule just before basic preparation of the soil for winter. In this way, the decomposition of the manure and mineralization of nutrients is delayed until the vegetation period of the following year. Applying manure in springtime is generally not recommended; it comes into consideration only on light soils in humid conditions (especially in highland and upland regions).

Dosage of manure of average quality in tons/ha (Škarda 1982, abridged):

Crops	Soil type		
	Light – medium Sand – sand-loamy	Medium – heavy Loamy – clay	Very heavy clays
Cereals + intercrops	15 – 20	15 – 20	20
Root crops	30	35	45
Annual fodder crops, oil crops	25	30	40
Vegetables (1)	35 (45)	40 (50)	50 (60)

Larger amounts are applied for vegetables with a high nutrient demand (cauliflower, late cabbage and kale, fruiting vegetables)

Slurry

In the past, slurry gained a bad reputation because of poor quality (low solid content), unsuitable stabling methods (permanent grid floors) and undisciplined methods of application (forced application harmful to the environment).

Good quality slurry is an efficient fertilizer of universal usefulness. Slurry itself is a fast-acting fertilizer (close ratio C:N, averaging 5:1). When applied with straw the efficiency of slurry is comparable with that of manure or compost. An excellent triple-combination is the use of slurry worked into the ground with straw and sown with a green manure crop.

With regard to restricting the loss of nitrogen during application, it is essential to work the slurry into the ground immediately. The least nitrogen loss is achieved through use of a special applicator which puts the slurry under the soil surface (harrow adaptor, incorporator).

Slurry is suitable for re-fertilization in the vegetation period either by working it into the soil during inter-row cultivation (special weeding hoe) or with a trailing-pipe applicator. Application by spraying on vegetation is suitable only for permanent grassland, if possible before rain. For application during vegetation, slurry is diluted with water to the ratio 1:1 (if it hasn't already been diluted using a large quantity of process water). Slurry is also very useful in the production of compost.

Urea

Urea is a fast-acting nitrogen-potassium fertilizer. It is of universal usefulness, especially suitable for re-fertilizing crops with a high demand for nitrogen and potassium (food wheat, maize, root crops, kale crops, celeriac etc.). The principles of application and possible uses are the same as for slurry. Dung-water has the same uses as urea.

Straw

Cereal straw has a typically high proportion of carbon to nitrogen (C:N = 60-90:1). It is therefore necessary to alter this ratio with the application of slurry or urea to a quantity of 10kg N per ton of straw (C:N ratio around 25:1). Before working the straw into the ground it should be shredded and spread evenly, ideally at the time of harvest (adaptor on the threshing machine). When applied with slurry, or perhaps with green fertilizer, straw is as effective as good quality manure. When straw alone is applied, we can expect competition for nitrogen from the microbial population (with prevailing immobilization of N and formation of more stable organic material) to the detriment of the plants' nitrification.

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Composts

Compost is a fertilizer with universal application without any danger of significant loss of nitrogen, as is the case with farmyard manure. Its use should be given preference on very light soils (ready form of nutrients, does not compete for water with plants and soil biota, stabilized organic matter). When using compost for re-fertilizing during the vegetation period, it should be worked lightly into the soil e.g. by hoeing or tine-harrowing. Compost is an ideal fertilizer, the disadvantages of which are the relatively high cost of production and the demand put on knowledge and adherence to production methods.

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Modern application of slurry with minimal loss

7.5 GREEN MANURING

In organic farming, green manuring plays a significant role due to the increase in the quantity of rapidly decomposing organic matter in the soil, the influence on soil biota activity, nitrogen fixation, improvement of the physical and chemical properties of the soil, improved nutrition of following crops etc. By green manuring we mean the intentional cultivation of a crop to be ploughed into the soil as organic fertilizer. Growing crops as green manure enables us to:

- increase the content of rapidly decomposing organic matter in the soil.
- increase the fixing of nitrogen (through the use of clovers and legumes).
- increase the activity of soil biota.
- improve the nutrition of following crops.
- increase the humus content of soil (when ploughed in with straw from precrop)
- improve the physical and chemical properties of the soil.
- limit soil erosion.
- limit the loss of nutrients (especially nitrogen).
- control weeds (working the soil, shading).
- restrict disease and pests – improving precrop value (phytosanitary effect).
- use it for fodder (if necessary).

METHODS OF GREEN MANURING

Green manure as main crop

This method is used when it is necessary to thoroughly fertilize the land with organic matter or to get rid of weeds (generally at the start of conversion or in the case of serious problems with persistent weeds), on organic farms without livestock and on specialist organic farms (vegetable production etc.).

Intercrops

Undersowing

The advantage of this method is the lower cost of establishing a crop (established along with the main crop or only sown in addition to the main crop). The land must not be heavily weed infested as it is not possible to use mechanical weeding techniques after undersowing. A disadvantage may be in competition with the main crop when the green manure crop grows too vigorously, or, vice versa, when the main crop suppresses the undersown crop.

Crops suitable for green manuring are shown in the following table (Rozsypal, 1994):

Crop	Seeding amount kg/ha	Latest sowing date
White clover, *Trifolium repens*	8–10	31st August
Crimson clover, *Trifolium incarnatum*	25–30	15th August
Alsike clover, *Trifolium hybridum*	10–12	10th September
Field pea, *Pissum sativum* ssp. *arvense*	150–260	30th September
Broad bean, *Vicia faba* ssp. *vulgaris*	140–250	31st August
Common vetch, *Vicia sativa*	140–170	15th August
Winter vetch, *Vicia villosa*	120–140	30th September
Hungarian vetch, *Vicia pannonica*	175–195	30th September
Italian ryegrass, *Lolium multiflorum*	30–45	15th September
Westerwold ryegrass, *Lolium multiflorum*, var. *westerwoldicum*	30–50	15th August
Lacy phacelia, *Facelia tanacetifolia*	10–12	15th September
Sunflower, *Helianthus annuus*	20–25	31st July
White mustard, *Sinapis alba*	8–12	31st August
Oilseed rape, *Brassica napus*	8–10	10th September
Winter Wild turnip, *Brassica rapa*	8–12	15th September
Spring Wild Turnip, *Brassica rapa*	8–10	15th August
Buckwheat, *Fagopyrum vulgare*	70–100	15th September
Winter rye, *Secale cereale*	140–170	30th September

Lacy Phacelia is a prospective intercrop also for its phytosanitary effect

Stubble field intercrops

Immediately after harvesting the main crop a green manure crop is established. The disadvantages are the higher cost of establishing a crop (preparation of soil for sowing) and the risk of poor growth in the event of dry weather (rolling is advisable after sowing). Using this method, weeds are very effectively suppressed (working the soil and shading). When an intercrop is sown in a stubble field the intensity of work on the land is reduced to the absolute minimum to retain moisture (low-impact and soil-protection methods). Ploughing is used only in the event of infestation by persistent weeds. If there are no such problems with weeds, the cost of establishing the intercrop and the risk of a lack of moisture can be reduced by sowing directly into non-worked soil.

Undersown crops

Undersown crops are grown between rows in orchards and vineyards. The crop is sown in autumn or spring and in June or July it is mulched and worked into the ground during autumn or spring work. With young plantations, undersown crops are only used in well irrigated conditions (without irrigation the green manure crop can compete for water and harm the planted fruit varieties).

Conditions for use of green manuring For successful cultivation of a green manure crop, the intercrop period must be at least 45 – 60 days from the time of sowing, whilst moisture of soil and rainfall should be adequate for the emergence and growth of the plants.

Green manure is often grown as a combination of plants. Possible examples are given in the following table:

Combination	Sowing amount kg/ha	Combination	Sowing amount kg/ha
Summer and stubble-field intercrops			
Winter oilseed + mustard	6 + 5	Sunflower + field pea	8 + 70
Oilseed(wild turnip) + mustard + phacelia	5 + 5 + 2	Winter oilseed + buckwheat	6 + 60
Ryegrass + oilseed	10 + 10	Oilseed (wild turnip) + mustard + vetch	5 + 5 + 35
Hungarian vetch + phacelia	100 + 6	Vetch + phacelia	80 + 6
Field pea + common vetch + mustard	80 + 60 + 5		
Winter intercrops			
Italian ryegrass + winter vetch + crimson clover	20 + 50 + 20	Oilseed + Hungarian vetch + Italian ryegrass	10 + 40 + 20
Oilseed + rye	5 + 120	Italian ryegrass + Hungarian vetch	20 + 100
Winter vetch + rye	50 + 110	Field pea + winter vetch + rye	50 + 50 + 100
Undersown crops			
Italian ryegrass + white clover	14 + 9	Bird's-foot-trefoil + Italian ryegrass	7 + 22
Italian ryegrass + oilseed (wild turnip)	12 + 8	Italian ryegrass + White clover. + oilseed	12 + 3 + 4
Mixes for less fertile sandy soils			
Yellow melilot	25	Winter vetch + lupine + phacelia	20 + 60 + 10
Crimson clover + Italian ryegrass + rye	20 + 10 + 30	Winter vetch + crimson clover + rye	50 + 15 + 40

With a shorter intercrop period, or a lack of irrigation, cultivation of green manure becomes pointless as there is insufficient growth of biomass and there is a risk of weeds multiplying.

On dry land, and in a dry year, there is a danger of reduced yield from the subsequent crop due to depletion of water from the physiological soil profile. This is especially true for dry regions, for light, drained soils and for shallow soils in drained areas (shallow soil on a gravel-sand layer etc.). In these situations, priority is given to establishing the green manure plant as an undersown crop with the main crop, and green manure is not scheduled before a winter crop.

If another crop is to be sown in the same year after ploughing in green manure, the quantity of biomass worked into the soil should not be too great. Large quantities of green manure can cause irregular development of the following crop due to the phyto-toxicity of intermediate products of organic decomposition, competition for water and worsened contact between seed and soil. The closed stand of the green manure should not be more than 0.2–0.3 m. With a heavy yield, the green manure should be worked into the soil at least three weeks before sowing the following crop. Such a heavy crop should first be shredded, spread evenly over the land and left to wither. A high amount of freshly worked green manure can be tolerated only by potatoes and irrigated root-ball vegetable seedlings.

7.6 FERTILIZING WITH MINERAL FERTILIZER

In organic farming, plant nutrition is based on the cycle of nutrients between soil, soil biota and plants. The decisive factors in achieving a steady balance are the fixation of airborne nitrogen and the production and treatment of farmyard manure. Due to the procedural losses and the sale of organic produce, there is a partial loss of nutrients from the cycle. It is necessary to analyse and balance the soil by renewing soil nutrients in the form of mineral fertilizer (stable balance of nutrients).

The range of mineral fertilizers is defined by legal rules. Generally speaking, the only fertilizers that can be used are those of natural origin which have been physically processed (shredding, grinding, granulation).

Nitrogen (N)

Soluble mineral nitrogen fertilizers are not permitted in OF (nor is e.g. Chile saltpetre). The balance of nitrogen is ensured by the symbiotic and non-symbiotic fixing of molecular airborne nitrogen. In this respect it is necessary to include clovers and legumes in the crop rotation or to have clover present in permanent grassland. Care of the soil is of great importance because symbiotic and free-living fixers of molecular nitrogen are aerobic organisms and require structured, well-aerated soil of optimal reaction.

Phosphorus (P)

As a source of mineral phosphorus we can use ground phosphates (usually granulated) and Thomas meal. Phosphorus fertilizer is preferably worked into the soil with organic fertilizer. It is beneficial to apply ground phosphate (also other ground minerals) to bedding material, to stored manure (to restrict the loss of nutrients, especially nitrogen and improve the stable microclimate) or when establishing compost (to create an organic-mineral complex).

Potassium (K)

The source of potassium is natural potassium salts – chlorides, sulphates and mixtures of these (sylvines, kainite, carnalite, polyhalite). When fertilizing with potassium it is necessary to take into account the ratio of potassium to magnesium (K:Mg), as well as an agrochemical soil test, as this is significant with regard to animal nutrition. As with phosphorus fertilizer, potassium fertilizer is preferably worked into the soil along with organic fertilizer.

Magnesium (Mg)

The source of magnesium is natural magnesium sulphate and kainite salts as well as dolomitic calcite and dolomites. To improve the reaction of the soil (pH) preference is given to the use of magnesium in the form of dolomitic calcite (dolomite).

Calcium (Ca) and soil reaction (pH)

Calcium is applied to improve the pH of the soil. Ground limestone is used or dolomitic calcite (if magnesium is needed). Oxide forms (quicklime and hydrated lime) are not permitted. The optimum pH varies according to the type of soil and cultivated plant. Calcium is always applied separately from farmyard manure with a gap of at least one month. To eliminate an acute deficiency of calcium in fruit varieties (bitter pit in apples), whitewash or calcium chloride can be used.

Trace elements

Trace elements are applied only in the event of a proven deficiency (symptomatic or according to soil analysis). Technical salts of individual trace elements are applied as fertilizer (usually sulphates).

Helpful soil substances

Microbial fertilizer contains the roots of symbiotic rhizobiae specific to individual plants. The results cannot always be proven, but their use is definitely recommended when growing soya for the first time on a given piece of land.

Helpful soil substances

Humic acids and fulvic acids, microbial fertilizers (*Azotobacter, Bacillus megatherium, Azospirillum braziliense, Agrobacterium),* endomycorrhizal fungi.

Fertilizer and helpful soil substances must only be used in accordance with EU Council Regulation 834/2007, Annex 1 and in accordance with agricultural legislation of member states.

7.7 NUTRIENT BALANCE

The nutrient balance can generally be described as the relationship between source and consumption. Assessment of nutrient balance in agriculture is one of the basic judgements that

According to EU Council Regulation 834/2007, Annex I, the following fertilizers and helpful soil substances (incl. organic fertilizer) can be used in organic farming:

Name (mixed products or products containing the following materials)	**Name (mixed products or products containing the following materials)**
Dung	Wood ash
Dried dung and dehydrated poultry droppings	Finely-ground phosphate
Composted poultry excrement, including poultry droppings and composted dung	Calcium aluminium phosphate
Liquid animal excrement (slurry, urea etc.)	Basic slag
Composted or fermented domestic waste	Raw potassium salt (e.g. Kainite, sylvine etc.)
turf	Potassium sulphate, which may contain magnesium salt
Clay minerals (e.g. perlite, vermiculite etc..)	Distillery slops and distillery extracts
Waste from mushroom cultivation	Natural calcium carbonate (e.g. Chalk, marl, ground limestone, cretaceous marl)
Excrement from worms (worm compost) and insects	Natural calcium carbonate and magnesite (e.g. Chalk, ground limestone containing magnesium)
Guano	Magnesium sulphate
Composted or fermented mixtures of plant material	Calcium chloride solution
Products or by-products of animal origin (blood meal, powdered horns and hooves, bone meal or de-gelatined bone meal, fish meal, meat meal, feather meal, meal made from animal hair and skin, wool and fur)	Calcium sulphate (plaster)
Milk products	Sugar production waste
Products and by-products of vegetable origin for fertilizing (e.g. Meal made from oil cake, cocoa pods, brewery by-products etc.)	Sulphur
Sea-weed and sea-weed products	Trace elements
Saw-dust and wood chips	Sodium chloride
Composted bark	Rock flour

the farmer must make. In the event of a long-term positive balance (excess) this can lead to financial loss and to significant change in the soil environment (this may be seen e.g. in the case of increased magnesium or sodium in the soil leading to devastation of the soil structure). In the event of a long-term negative balance (deficit) the soil is deprived of nutrients (pillage farming methods) leading to its acidification, destruction of the sorption complex and, thus, to an irreversible change in its fertility.

Nutrient balance can be calculated for the entire farm. This calculation is necessary for planning purposes. To improve farm efficiency and make detailed decisions, the long-term balance is required for each individual plot of land. From the ecological viewpoint it is good to record balances according to geographical units – nowadays the balance is carefully observed according to individual catchment areas. The nutrient balance of a field is influenced by harvesting, fertilizing and working the soil. As well as the remains of cultivated crops, a significant source of nutrients in agricultural soil is organic fertilizer, while in conventional farming it is mineral fertilizer. Nutrients also come into the soil from atmospheric precipitation and from the weathering of rock and minerals.

In calculating the balance, it is necessary to anticipate losses due to leaching of nutrients from the soil profile, erosion and denitrification. According to the result of the balance, a basic, general decision should be made (this must then be refined for individual nutrients).

If the balance is positive and the possibility of increasing yield using other varieties and farming methods has been tried, then it is necessary to restrict inputs as the other agro-ecological conditions (climate, water system, soil type) do not allow the nutrients to be used up by greater yield.

If the balance is negative there are two possible options:

- increase the supply of nutrients (more organic fertilizer),
- make a long-term change to a lower level of yield to lower the withdrawal of nutrients from the field.

The nutrient balance can be changed in either direction by altering the crop rotation.

What to include in calculating the nutrient balance and where to find the information:

- **nutrients released through weathering of rock and minerals.** It is necessary to anticipate that the more the soil is aerated as a result of ploughing, crop cultivation or even seasonal effects, the more intensive will be the weathering. To a greater extent it is possible to estimate, on a theoretical basis, that e.g. in Czech conditions, weathering releases a yearly quantity of up to 3 kg P, 12 kg K, 48 kg Ca and 13 kg Mg per ha. However, there is as yet very little data and the results of nutrient release by weathering cannot be deduced from the results of lysimetric or melioration water analysis, as is often carried out.
- **nutrients supplied by the atmosphere.** Research into this category is now being carried out in many locations and data can be obtained for individual regions e.g. of the Czech Republic from the network of the Czech Hydro-meteorological Institute, the Agricultural Water Management Authority or the Central Institute for Supervising and Testing in Agriculture. For illustration purposes we give the results of 20 years of observation by ACHP Kroměříž on a site in Holešov, where an average of 7kg nitrous N, 13 kg ammonia N, 5 kg P, 8 kg K, 31 kg Ca and 15 kg Mg fall on 1ha in a year.

Another category is that of **nutrients released in the break-down of crop residue** after cultivation. The amount of such nutrients is naturally dependent on the yield in individual years. It is very difficult to determine and recorded data varies. The intensity of mineralization is also not precisely known and it is usually considered along with nutrients released after all residue has broken down. For long-term calculation of the mineral balance, the values given in the following table are accurate enough (Čvančara 1962, adapted) (kg/ha):

	N	P	K	Ca
Cereals	30-40	10	20	60
Legumes	70	10	10-15	60
Clovers	150	20	40	100-150

- **nutrients are also supplied by organic fertilizer** (kg nutrient per ton of fertilizer) see following table:

Fertilizer	N	P	K
Matured manure	5,0	1,3	5,0
Compost	7,4	1,9	9,0

From the positive categories (supplying nutrients) we will now move to the categories typical for their depletion – the negative categories.

The first of these is the withdrawal of nutrients by harvesting. The following results are from work done by J. Neuberg J. (1990): *Complex method of plant nutrition* and simplification for main crop groups (kg/t main product):

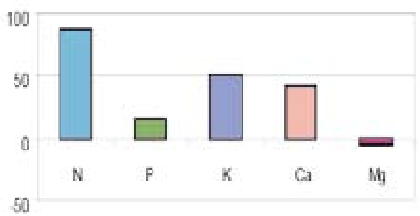
	N	P	K
cereals	25	5	20
legumes	60	8	35
clovers	25	3	13

Another significant category of loss is **nutrient washout (leaching)**. The most widespread results for central Europe are given by Müller (1980) (kg/ha):

Type of soil	N	P	K	Ca	Mg
light	15–25	0–5	7–17	110–300	17–43
medium	9–44	0–5	3–8	21–176	9–16
heavy	5–44	0–5	3–8	72–341	10–54

The data given here should be sufficient for calculation of balance in individual years on individual plots. With regard to long-term sustainability, it is necessary to calculate over a long period and confirm the results with soil tests, in which the level of nutrients and organic material is assessed. Checking the quality of humus is an essential part of this.

The chart shows the nutrients available to the following crop. By comparing with the table showing the plants' withdrawal of individual elements, we find that the supply of nutrients is sufficient for a yield of approximately 3.5 tons of cereal per hectare or almost 2 tons of rapeseed.



Amount available to the following crop (kg/ha)

In a similar way we can carry out calculations for other crops and plots of land, or even the whole farm.

Nitrogen plays a significant role in the nutrient balance. Here is an example of nitrogen balance (kg/ha) for a specific crop rotation:

- clover-grass mix
- clover-grass mix
- winter wheat
- oats/legumes
- potato
- rye

V obrázku vlevo (po směru h.r.):

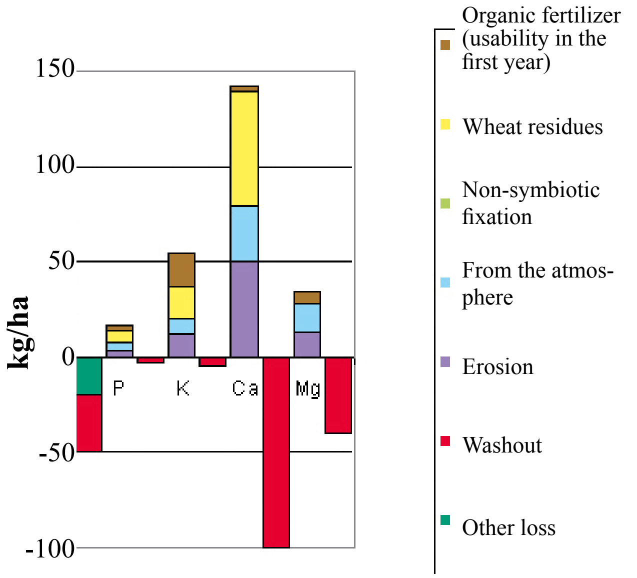
Need for N within 6-year crop rotation (670 kg/ha)

Clover-grass mix 150 kg/ha

Clover-grass mix 150 kg/ha

As an example, we give the nutrient balance for a field where winter wheat was grown and farmyard manure was applied (kg/ha):

Nutrient balance on a field after winter wheat cultivation and farmyard manure application (kg/ha)



Winter wheat 100 kg/ha

Oats/legumes 70 kg/ha

Potato 100 kg/ha

Rye 100 kg/ha

V obrázku vpravo (po směru h.r.):

Sources of N in 6 years 705 kg/ha

Crop residues 210 kg/ha

Organic fertilizing 225 kg/ha

Fixation of N 270 kg/ha

NEVÍM K ČEMU PATŘÍ? V ČEŠTINĚ UŽ NIC NEBYLO

From the given example, with high representation of crops taking nitrogen from the air and with a load of about 0.8–1 LU/ha, a stable balance of nitrogen is evident. Quite a different situation may arise from a crop rotation system with a higher proportion of commercial crops and with very little or no livestock production.

If we opt for a crop rotation system without livestock production: legumes, potatoes, winter wheat, oats, peas, winter wheat + mixed crop, then the nitrogen balance will be different from the previous example. According to calculation, the nitrogen supply for the 6 year crop rotation will be 290 kg/ha, while the required nitrogen will be 463 kg/ha. In this situation the nutrient deficit must be remedied – for example by buying farmyard manure and applying it to the potatoes, or even to other crops. A similar problem with a negative balance occurs with potassium. This problem can also be solved by using organic fertilizer. The question is the practicality of buying fertilizer from another organic farmer. If this is not realistic, then the crop rotation system must be changed.