BASIC GUIDE

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THE ORGANIC RESEARCH CENTRE
ELM FARM

The Basics of Soil Fertility

Shaping our relationship to the soil

The enhancement of soil fertility was a crucial value already to the pioneers of organic farming, but the conservation of fertile soil is not always given enough attention. And yet organic farming depends on good natural soil fertility. Exhausted and damaged soils cannot offer the desired performance. The cultivation of soil fertility requires a lot of care.
This booklet offers a view on soil fertility from different angles. It deliberately avoids offering universal 'instructions', but rather seeks to provide information to stimulate new thinking about a sustainable relationship to the soil.

2016

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OK NET arable

Why Talk About Soil Fertility?

In cultivating the land, we live from and with soil fertility. An ecologically vital soil is continuously restoring its productivity. If we neglect its needs, it suffers as a result. The soil loses vitality, and becomes more sensitive to weather and erosion; harvests decline. In organic farming, damage cannot be offset by purely technical means. This is why an exhausted or degraded soil requires recovery by means of ecologically sensitive actions, which help the soil to regenerate on its own. Despite the practical constraints and problems, many possible actions are available enabling us to act according to our responsibility as farmers for a living soil. It is worth it, not only financially.

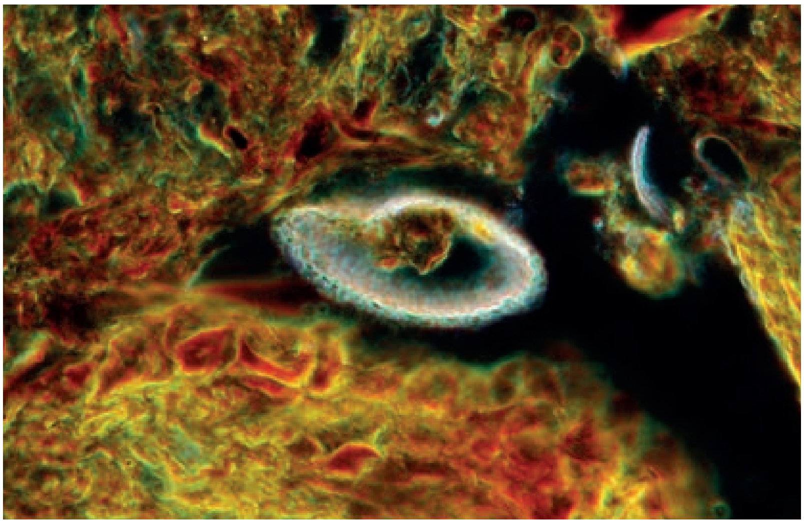
In the 1960s, scientist Ernst Klapp defined soil fertility in a practical sense as "the natural, sustainable ability of a soil to produce plants". He described it as the ability of the soil to provide everything for stable yields without external aid. Since then, agricultural science has widely been replacing the comprehensive term soil fertility with a multitude of physical, chemical and biological variables. One of the current tasks of science is to render such detailed knowledge applicable to farming practice.

Many practitioners have developed their own strategies and techniques for the care of soil fertility. They have learnt through observation, and relied on their intuition. Such experience and the knowledge gained via scientific experiments and observations complement each other well. This booklet aims to stimulate the practice of a truly sustainable culture of a fertile, living soil, based on well-tried fundamentals, as well as on the testing of new possibilities.

The editors

» We feel that in many areas, simple cause-and-effect observations do not match up to our actual living environment. This is why it is more timely and necessary than ever to see the soil as a complex organism instead of a simple chemical-mechanical model.

Thomas Fisel, advisor Bioland



The microsphere is a wonderful habitat. In the centre of the picture: a single-celled organism.

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Part 1: Principles of Soil Fertility

1.1 The soil of pioneers

Organic farming has developed as an agricultural approach since the beginning of the 20th century. However, its historical roots are as old as agriculture itself. For several decades, organic farming was practised and developed only on a small network of farms. The 1980s and 1990s saw increased recognition, and newcomers to organic farming. Before introducing the reader to current knowledge about good treatment of soil fertility from a holistic point of view, based on scientific and practical information, we would like to acknowledge its roots with the help of a few quotes from the early pioneers:

Influences of soil biology

The farm owner Albrecht THAER recognised (1821): "Much in the way that organic matter is a product of life, it is also the precondition of life." And while most researchers were turning towards agricultural chemistry, Charles DARWIN discovered a fact most crucial for organic farming (1882): "The plough is one of the oldest and most valued inventions of man, but, long before its existence, the land was regularly ploughed by earthworms."

At the beginning of the 20th century, new microscopes were tapping into the inconceivable diversity of soil life, and an ecological way of thinking started to develop. Richard BLOECK (1927) wrote: "Through the activity of microscopic life, arable land became a real living being." The image of a cycle reoccurred. The Swiss farmer Alois STÖCKLI wrote (1946): "…persistent and increasing soil fertility depends on the condition of a cycle of the substances", yet "in many places there is resistance against accepting the integral role of organisms in the soil in this context". One of the co-founders of organic farming, Hans-Peter RUSCH, regarded the cycle of life to be essential (1955): The "living substance" is "introduced to each living being in the substance cycle". The agronomist Franz SEKERA emphasised (1951): "The tilth (optimum soil condition) is defined as the biological engineering of the crumb structure by soil-inherent microorganisms."

Ideological ideas and influences

Rudolf STEINER taught the following during his agricultural course (1923): "One needs to know that fertilisation must consist in life-promotion of the soil. … And in the seed we gain an image of the universe as a whole." In England, Lady Eve BALFOUR (1943) stated that only ecology associated with Christian values may help us realise "that all in the heavens and on earth is only part of one whole", and further, that "the health of the soil, plant, animal and human is one and indivisible." Her agricultural colleague Sir Albert HOWARD observed (1948) that "Mother Earth never tries to do agriculture without animals; she always cultivates mixed cultures. "Organic farming is supposed to adopt Mother Earth's natural agriculture method." Mina HOFSTETTER (1949), a Swiss pioneer of organic farming, regarded the feminine qualities of the earth to be a key to a deeper understanding of soil fertility. Mother Earth may speak directly to the female farmer if the latter finds peace and quiet to listen: "…she will teach us again, or wipe us out."

Why the terms 'organic' and 'ecological' farming?

The 'Bio-logy' (i.e. the logos of life) of organic farming was literally understood as a 'life teaching' by its founders, i.e. as a holistic life and farming philosophy. Rather than concentrating on chemical substances, they focused on cohabitations of individual beings or 'ecosystems', which on a higher level were perceived to be a unit in the whole, i.e. an 'organism'. Hence organic farming uses the terms soil organism, farm organism, organism earth, as well as soil, farm and earth as an ecosystem. Not to replace the interaction and the steady continuation of natural and social life by technology, for many against the backdrop of an interaction with spiritual, divine influences, was believed to be essential. Exemplifying the interconnectedness of all things, the following guiding principle was coined: "Healthy soil – healthy plants – healthy humans." This idea is still key in our day, and stated for example in the principle of health, one of the four principles of Organic Agriculture defined by IFOAM (2005).

Nikola Patzel

» **Soil fertility is the indispensable foundation of agriculture, not oil. This is why the soil belongs in the hands of those who nurture it, not those of speculation. In order to cope with the challenges of the 21st century, practical knowledge gathered by farmers and scientific knowledge of academia must come together better.**

Jürgen Hess, University of Kassel, Witzenhausen, Germany

Rudolf Steiner 1861-1925

Albert Howard 1873-1947

Mina Hofstetter 1883-1967

Maria Müller 1894-1969

Eve Balfour 1898-1990

Hans Peter Rusch 1906-1977

1.2 Soil fertility – A term undergoing change

With the emergence of applied agricultural sciences, a soil's yield was regarded to be its essential fertility measurement. The soil's nutrient content (mainly nitrogen, phosphorus and potash) was interpreted as a fertility indicator – until artificial fertilisers came to be seen as being available on demand and substituted self-reliant soil fertility in the eyes of many. But with dwindling resources, the discussion of the term is moving yet again in another direction. The efficiency of nutrient cycling in the soil – especially within the cycle – for plant yields as a way of measuring soil fertility is returning to the foreground.

Soil fertility is an ecological life process

The soil is habitat to an immense variety of microorganisms, animals and plant roots. A fertile soil bears healthy crops over generations with its low demand for external inputs such as fertilisers, pesticides and energy. In a fertile soil, soil organisms efficiently turn nutrients and organic matter into plant yields, build up organic matter, protect the plants from diseases, and make the soil crumbly. Such a soil can easily be cultivated, absorbs rain water well, and withstands capping/siltation and erosion. A fertile soil leads via its filtering to clean groundwater and it neutralises (buffers) acids which reach the ground surface through polluted air. A fertile soil also quickly breaks down harmful substances such as pesticides. Moreover, a fertile soil represents an efficient reservoir for nutrients and carbon dioxide. It thus prevents overfertilisation of rivers, lakes and seas and contributes to reducing global warming.

In the view of organic farming, soil fertility is mainly the result of biological processes, and not of applied chemical nutrients. A fertile soil reacts actively with the plants; it structures itself and is capable of regeneration.

In such 'earthworm towers', clay–humus complexes and earthworm mucilage work rather visibly towards soil cohesion.

Balancing the appreciation of the soil's functions and the demand that it 'functions'

Today, the term 'soil quality' is sometimes used instead of soil fertility. Soil quality is the sum of all socially valued functions of the soil. This perspective may help to extend attitudes to the soil into new areas. Nevertheless one needs to appreciate that the definition of soil quality determined by soil functions always depends on contemporaneous economic and/or political constraints. The most important natural soil functions are:

- **Production function:** Yields that suit local conditions.
- **Transformation function:** Nutrients are efficiently turned into yield.
- **Habitat function:** Living space for an active and diverse flora and fauna.
- **Degradation function:** Degradation/transformation of plant and animal residues, and thereby closing the nutrient cycle.
- **Self-regulation function:** No danger of being permanently thrown off its healthy balance – e.g. efficiently 'digesting' or suppressing pathogens which penetrate the soil.
- **Filtering, buffering and storage function:** Retaining and breaking down harmful substances; keeping nutrients in the soil; storing carbon dioxide.

Paul Mäder

Perspectives and definitions of soil fertility

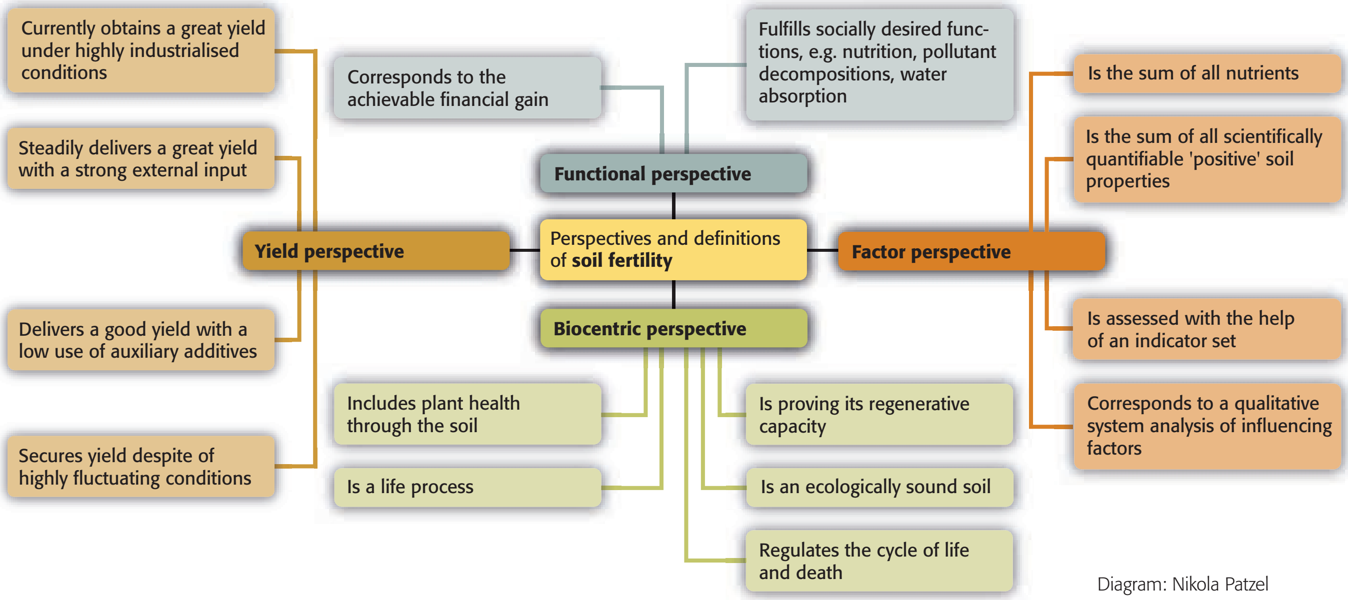


Diagram: Nikola Patzel

There are many perspectives and definitions of soil fertility in agriculture. Are we assessing the soil itself (biocentric) or that which we demand from it (functional)? Do we measure soil fertility on the basis of the yield or of different properties of the soil itself?

Scientific analysis of fertile soil

As an alternative to purely nutrient chemistry, for a long time there were efforts to detect the fundamentals of soil fertility with organic matter chemistry, attempting to elucidate and classify organic matter directly via its chemical structures. Such attempts were unfruitful. Today we focus on other properties: the availability of nutrients, the carbon/nitrogen (C/N) ratio of organic matter, as well as the transforming and recycling activity and the organic matter quality of the soil. They all serve as a measure for …

- nutrients directly available to plants. Which elements are to be found in a heated-water extract of the soil?
- readily available nutrients in the life cycle. What is the size of microbiological biomass, and what is its C/N ratio?
- organic matter stability (stable organic matter is heavier and immature organic matter). How complex are its molecular assemblies, and what is it's density?

Paul Mäder

1.3 What does soil fertility mean in organic farming?

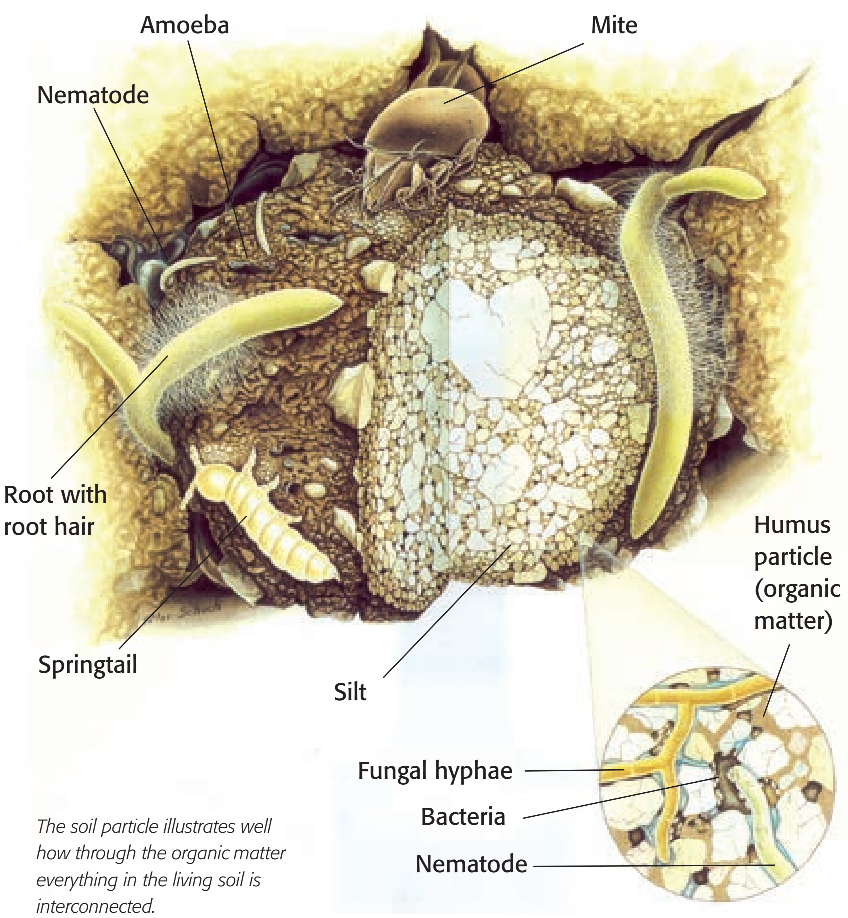
For organic farming, 'soil fertility' primarily means a characteristic of the living soil. As soil fertility is a feature of the never quite transparent soil organism, we may never fully understand it on an intellectual level, nor fully quantify it by measurements alone, similar to our understanding of human beings. This is why we talk about soil fertility in the context of a holistic acknowledgement of the soil and its impact on plants, as well as the analysis or measurement of individual characteristics.

The diagnoses and measures in this booklet are concerned with possibilities of observing the soil and describing it with regard to individual qualities:

- **Physical qualities** can be recognised e.g. via a spade test. A physically sound soil offers living and working space for all soil animals and plant roots, with sufficient air for respiration. It is the farmer's responsibility to stabilise the soil structure with plant roots, to make it viable and to avoid compaction by gentle use of machines.

» Unfortunately, our current society is distanced from nature, and only a minority of people is aware of the importance of a sound and intact soil. The high use of chemicals in today's conventional agriculture will in the future be labelled as a flash in the pan, as it is neither soil-improving nor life-enhancing. Only high soil fertility will guarantee sustainable and sufficient nourishment for humanity.

Jean-Louis Colling-von Roesgen, organic farmer on the Karelshaff, Luxembourg



The soil particle illustrates well how through the organic matter everything in the living soil is interconnected.

- **Chemical qualities** are determined through measuring individual nutrients and possibly also pollutants, and e.g. the pH value (calcium oxide/acid levels). A chemically well-appointed soil-plant organism has all necessary chemical elements and organic compounds available for its nourishment. Complex metabolites of different organisms enhance the plant's immune response. By returning extracted nutrients, we are trying to support these qualities in a healthy balance. In the case of previous overexploitation, the soil first needs to be balanced out.
- **Biological qualities** of the soil we are able to see in its transforming/recycling activity, the occurrence and visible evidence of life forms in the soil. The cohabitations are robust and active at the right time. Within the self-regulating ecological balance, all the animals, plants and microorganisms are working symbiotically. It is our job as cultivators to understand soil ecology well enough to be able to create or restore the conditions for a robust balance.

As a cumulative effect of its activities, cultivated fertile soil can produce good yields again and again. If this does not happen, we should observe the aforementioned soil qualities closely in order to identify irregularities.

The editors

1.4 The invaluable contribution of soil organisms

A fertile soil hosts a rich variety of organisms which are all taking part in important processes. Earthworms and insect larvae burrow through the uppermost soil layers in search of dead plant material. Their passages aerate the earth and the pores and passages are able to absorb water like a sponge. Springtails, mites and millipedes degrade plant litter. Microorganisms turn residue from animals and plants into valuable organic matter. Finally, bacteria convert organic residues into their chemical constituents, and predatory mites, centipedes, beetles, fungi and bacteria regulate organisms before they can become harmful.

A springtail (Collembola). No need to worry about the decomposition of plant litter in an intact soil.

Earthworms – Master builders of fertile soils

With a single generation and a maximum of eight cocoons per animal and year, earthworms reproduce at a rather slow rate. With a life expectancy of five to eight years they are however the most long-lived soil animals, and play a prominent role in the soil.

Earthworms produce 40 to 100 tonnes of valuable worm casts per hectare and year in Central European soils. This is equivalent to a soil growth of 0,5 cm for arable land, and 1,5 cm for grassland. The valuable material contains on average five times more nitrogen, seven times more phosphorus, and eleven times more potassium than the surrounding soil.

An intensive mixing of organic substance with mineral soil particles, microorganisms and mucous secretions of earthworms leads to stable crumb structures. The latter help to prevent the soil from silting up, and promote its cultivability as well as

> Learn to love your worm; it's the best livestock investment you will ever make on your farm.
>
> *Iain Tolhurst, organic grower near Reading, UK*

its nutrient and water retaining capabilities. In this way, earthworms loosen up heavy soils and make sandy soils more cohesive.

With their burrows, earthworms ensure a good aeration of the soil. Especially the stable burrows of vertically digging earthworms improve the absorption and storage of water significantly. Soils rich in earthworms absorb four to ten times the quantity of water of soils with fewer worms. This way, surface runoff and erosion can be reduced. Up to 900 meters of worm burrows can be found per square metre and to a depth of a metre in unploughed soils.

Earthworms break down up to 6 tonnes of dead organic material per hectare and year in the ground. At the same time, they are transporting soil material from the subsoil to the topsoil, thereby rejuvenating the latter. They are also promoting the colonisation and reproduction of useful soil bacteria and fungi in their passages and faeces. Once diseased foliage moves into the ground, harmful organisms inhabiting the leaves are degraded organically. Over 90 % of worm burrows are populated with plant roots. The latter can thus penetrate deeper soil layers without encountering resistance, and there find ideal nutritional conditions.

Soil-inhabiting species, such as earthworms, are the quiet master builders of soil fertility. Intensive tillage considerably reduces their populations.

The number of cocoons in the soil indicates good living conditions for earthworms.

Maintaining soil fertility on a stockfree farm

Our soils at Hardwick are sandy clay loams, a fairly useful soil type for the wide range of vegetable types that we grow within a seven-year stockfree rotation. We have over many years aimed to reduce tillage to the minimum needed in order to preserve the soil organic matter and avoid soil damage. This is not easy, primarily due to lack of suitable equipment for small scale vegetable systems. We make great use of green manures within the rotation, with almost 3 years of long term clovers/lucerne mixtures, as well as many overwintering and relay green manures slotted in around the vegetables.

Making good use of this fertility is a challenge in the context of land preparation ahead of planting and sowing crops. The plough is still the primary tool of cultivation at some points in the rotation to create a clean seedbed from heavy green manure crops. Timing is critical and all primary cultivations are done during the spring, immediately ahead of plantings to minimise periods of uncovered soil.

Due to the high usage of green manures and additional applications of woodchip compost during the fertility building phases in the rotation, our soil structure is very good with no problems of compaction. Earthworm populations play a major role in maintaining good soil structure.

Secondary cultivations are shallow, no more than 100 mm, except prior to potatoes when they are up to 150 mm. Power harrow is the preferred tool with some use of triple K spring tines and/or harrow comb for the creation of stale seedbeds. All tined implements including power harrow are round tines as opposed to knife blades, as the latter are particularly damaging to soil structure. The use of bladed implements causes smear and shear hence their avoidance. All cultivations are aimed at creating the best conditions for crop establishment and weed control using the minimum of force and soil inversion. And generally, we use a lot of relay green manures within established crops to maintain ground cover, enhanced biodiversity, nutrient trapping/fertility building and weed control.

Iain Tolhurst is an organic producer since 1976, organic advisor and tutor since 1984. He is a leading figure in both Organic and Stockfree Organic since its conception. His 8 ha vegetable farm is a commercial enterprise, but also acts as a demonstration unit and teaching centre for stockfree, agro-forestry and agro-ecological principles of production.

How to protect and promote earthworms

Farmers can contribute to the promotion of earthworms. The following are the most important points:

Tillage and mechanisation

- Ploughs and quickly rotating devices should only be used if essential, as they may kill many earthworms, depending on when the cultivation is done. The loss rate with ploughing is at about 25 %, with rotating instruments up to 70 %.
- At times of earthworm activity, March/April and September/October, (intensive) tillage should be avoided.
- Tillage of the soil in a dry or cold state is considerably less harmful to earthworms, as they will remain in the deeper soil layers.
- The soil should be turned as little as possible; when ploughing, do it only minimally with an on-land plough, to avoid compaction in deeper soil layers. Plant residues should be worked in only superficially; not buried in too deep.

> Ploughing results in loosening up the topsoil for a limited amount of time. The earthworms' influence is more profound and varied. They build an extensive system of channels which ideally supplies the soil and plants with water and nutrients.
>
> *Lukas Pfiffner, FiBL, Switzerland*

- Use minimal machining processes which are gentle on the soil as well as till and drill combinations. Avoid heavy machinery.
- Only cultivate completely dry, stable soils.

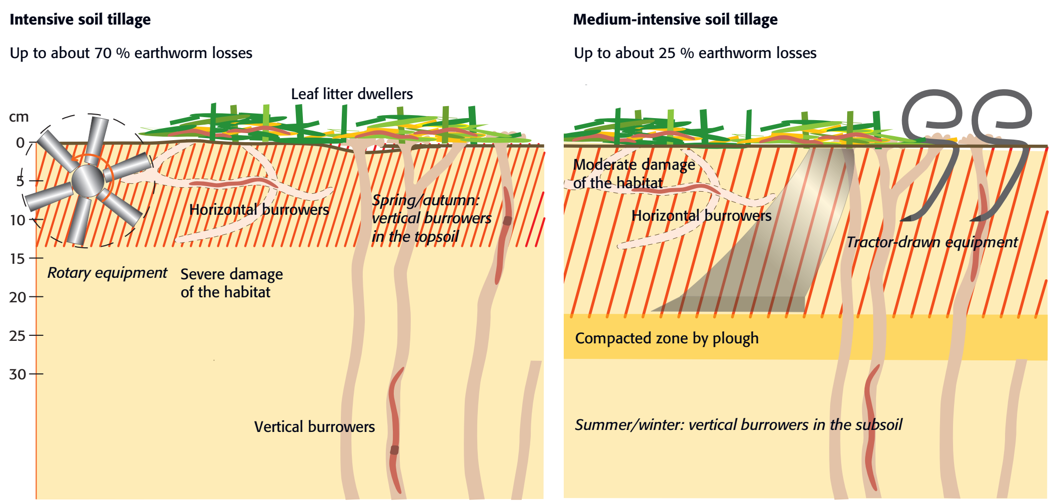
Crop rotation

- A long crop rotation with perennial and deep-rooting catch crops rich in clover or green manure, and varied harvest residues, offer abundant nourishment for earthworms.
- A plant cover, especially during winter, may promote earthworms considerably. Soil-regeneration periods, provided by the use of perennial meadows, are a godsend to earthworms.

Fertilisation

- A balanced and well cared for soil is beneficial to plants and earthworms.
- Slightly rotted manure or compost is usually more helpful than fresh manure to build soil organic matter, to reduce weeds, to speed the take-up when applied to grassland and to achieve long term nutrient supply.
- Organic fertilizer and manure should only be worked in superficially.
- Dilution and processing of liquid manure has a positive effect on earthworms. However non-processed liquid manure (ammonia!) may seriously damage earthworms and other beneficial organisms living in the soil surface layer.
- Liquid manure should only be applied on absorbent soil.
- Regular liming (according to pH values) is important, as most earthworms avoid soils with a pH below 5,5.

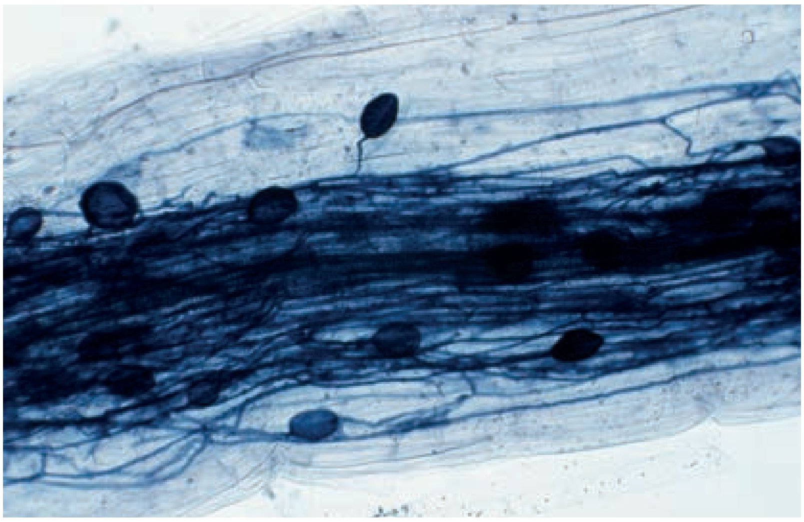
Effects of various intensive cultivation practices on earthworms



The more intensively the soil is cultivated, the higher the losses. In springtime and autumn losses are highest.

» I am always amazed how all the myriads of soil organisms know exactly what needs to be done. The great collaboration, which ultimately makes soil fertility possible, cannot simply be called coincidence, in my book. We ought to simply stand in awe.

Martin Köchli, organic farmer in Buttwil, Switzerland



Hyphae of an endomycorrhizal fungus with round storage organs (vesicles) in a plant root. The delicate hyphae may grow in the smallest of soil spores where they exploit nutrients and water. This way, mycorrhizae are able to multiply the roots' active surface, increasing the nutrient- and water intake. Fertilising, pesticides, and soil cultivation weaken the fungi.

Bacteria and fungi – underrated helpers

One gram of soil contains hundreds of millions of bacteria and hundreds of metres of fungal hyphae. The microorganisms (including the ones in animals' digestive tracts) are capable of breaking down plant and animal material into its basic components. They not only regulate nutrient cycles by breaking down organic matter, but are also capable of fixing nitrogen from the air and forming symbioses with plants. Bacteria and fungi are part of almost all mineralisation processes in the soil.

Mycorrhizae (root fungi) form a symbiotic relationship with plants, infest the plant root, and open up an extended soil area for the latter. Mycorrhizal fungi contribute further positive properties for the soil structure. They enable an exchange of substances between plants which are connected by them. Cultivation disrupts the fungal network in the soil. The mycelium regenerates however.

Lukas Pfiffner, Paul Mäder and Andreas Fliessbach

1.5 Using the potential for gentle soil cultivation

The extensive degradation of the soil started thousands of years ago with cultivation and intensive tillage, which were often associated with over stocking. The invention of steel and the introduction of the modern turning plough amplified this process with an intensive mixing of the soil. The use of tractors allowed for ploughing depths previously unheard of. In the past 40 years, intensive soil use has led to a loss of about 30 % of arable land through erosion.

The organic farming pioneers' motto was to loosen soil in greater depth and to minimally cultivate it, in order to maintain the natural soil formation. Efforts at reduced cultivation are therefore rather old in organic farming. The practical realisation of gentle soil cultivation in organic farming implied innovative technological developments at a very early stage. These include e.g. the Kemink system (soil loosening, fixed driving alleyway), the layer plough (the soil is ploughed in two layers), and the layer cultivator (the soil is tilled minimally, and the lower layer of the soil is loosened). However, a systematic investigation into reduced soil cultivation in organic farming only began about 20 years ago.

Experiments in organic conditions have shown that reduced cultivation brings about a further increase of the topsoil's organic matter content, that biological activity and soil structure improve, and that the ability to retain water available to plants is also increased. The latter fact is a particularly important yield factor during dry phases. Nevertheless, weeds – especially grasses and root-spreading weeds – and breaking up grass-clover without deep ploughing remain our key challenges.

» If you apply the system of reduced cultivation properly, especially depth-reduced cultivation, the life in the soil is promoted. If this effect is assisted by an appropriate crop rotation, it can help reduce subsoil compaction, offset negative effects seen with denser bedding in a previously ploughed ploughing layer, and facilitate a generally more stable soil. The surface becomes stronger with a higher content of organic matter, also because an increased number of fungi stabilise the aggregates.

Harald Schmidt, Foundation Ecology & Agriculture, Germany

This cultivator with a double-star roller is an alternative to the disc harrow. It loosens the soil in a deep or shallow manner. The machine offers the option of mountable straw feeder and harrow for an optimal incorporation of straw.

The necessity for an even gentler handling of the soil has prompted practitioners and researchers to look for new solutions for the problems of reduced cultivation. The use of an on-land plough alone is enough to help avoid compaction in the subsoil. Newer machines such as the Precilab plough, the Ecomat or the stubble slicer (highly modified skimmer) allow for shallow soil cultivation. Several non-turning systems, such as the Ecodyn cultivator, combine for instance extensive skimmer ploughshares with broad-standing, broadly positioned loosening tines. Even (no-till) direct drilling following green manuring has been successfully tried. Innovations in weed control are also expected to be delivered by robotics.

Climate change is a further push factor for systems rich in organic matter. Because of these innovations, organic farming has a chance to improve the productivity of arable farming by utilising biological processes, as well as to combat climate change thanks to carbon sequestration in the soil.

Paul Mäder

Producing living soil with reduced tillage

Richard Gantlett farms at Yatesbury in Wiltshire (534 ha of silty clay loam over lower grey chalk) growing cereals, vegetables and pedigree Aberdeen Angus cattle. For further reading visit http://yatesbury.webs.com/soil-life

The focus of all the work on our farm is to produce the best living soil that we can. I believe that a lively soil produces healthy plants and in turn healthy animals and people. That means sustainable, profitable crops. In my view there are four key ingredients to producing and maintaining a living soil: plant diversity, soil food, cow manure and cultivations.

I had been tinkering with cultivators for some time when I visited Manfred and Fredrick Wenz's farm in Germany, who have been farming organically for 30 years without a plough. This gave me the inspiration to give up ploughing myself in 2004. For me, ploughs encourage docks and couch and tend to lead to hard pans but most of all they bury good soil which I see as being counterproductive.

We sow pastures with as many different varieties and species as possible, which allows for different plant types to occupy different spaces in the soil profile and profit from soil variations across a field. These plants must then be allowed to fulfil their full potential by rotational grazing or cutting, allowing the leaves to go up and the roots to go down. The plants begin the process of harnessing the life-energy from the sun and transporting it down into the soil.

Cow manure is the most valuable initiator in the process of enlivening the soil. It brings all the right concentration of bugs and bacteria together to energise the soil into developing more vibrantly than without it. We use small quantities of very carefully composted cow manure, which we spread as far as possible with plenty of air and warm water. In addition, living organisms should be fed with plant material such as green manures and crop residues.

Our medium heavy soils require careful timing of soil cultivation, working wet soils will create house bricks and over working dry soils will create dust which will set like concrete. But the livelier we make the soils the more friable and easy to work and more rain tolerant they become.

A cut soil will often form a smooth sealed surface like a brick which will be resilient to weathering, whilst a tined machine breaks open a soil along weak points, which in turn lead to other weak points which weather easily. To maintain good aeration of the soil we tread it as lightly as possible with machinery. We use a selection of cultivators depending upon the need, a deep tine riper with forward pointing legs for lifting and aerating, a vibroflex heavy duty spring tine for aerating at shallower deeps with which we can also sow.

Give it a go, put some life-energy into your soil.

Part 2: Perceiving Soil Fertility

2.1 Direct observations

How can we evaluate soil fertility by simple means? There are several methods that have proven helpful, in the past and present. The main goal is to take your time and observe plants, the soil's surface, the soil itself and its inhabitants in more detail.

» Organic farming frequently requires the practitioner to often go out in the field with a spade and check the soil – I seldom see this put into practice though. I would welcome farmers engaging more with the complex system that is soil.

Harald Schmidt

Observing the plants
The cultivated plant is always the best indicator plant. If it thrives well and healthily over the years, the result will be a satisfying, high-quality yield. If such a result is achieved without the use of nitrogen fertilisers or chemical pesticides, we may assume high soil fertility. The strength of soil fertility becomes apparent particularly with unfavourable weather conditions over the whole year. Associated plants, such as thistles or chamomile, allow damage or signs of deficiency, such as compactions, to be revealed.

Interpreting the soil surface
The soil surface already gives indications of the state of the underlying soil. If it is protected by a vegetation cover, a surface crumbling emerges; the so-called biological engineering of soil crumbs. It can be recognised by its round soil crumbs, which also prevent excessive capping/siltation and erosion of the soil. This is why capping/siltation and erosion are indicators of a bad state of the soil. With increasing organic matter content, capping/siltation and erosion decrease.

Observing the soil life
The activity of earthworms and even smaller species, such as springtails, can be recognised by their exit holes on the soil surface. They can mainly be observed in springtime when organic mass has been lying on the soil surface ready for consumption by soil organisms. At that time, many small 'drill holes', as well as a few bigger ones can be spotted. With a cut of the spade, the channels can also be made visible in the topsoil crumb. Earthworm faeces on the soil surface, too, can indicate a high activity of this particular soil worker.

An indirect indicator of soil fertility is the speed at which plant residue decomposes. The easiest way is to observe straw decomposition. If during a vegetation period straw remains unaltered on the ground, it shows sparsely active soil life.

Smelling the soil
A fertile soil smells nice, not repellent. You can compare it with the smell of forest soil or field margins. If the soil smells of rot, something is wrong. Roots also have an inherent odour which derives from root excretions (exudates). Leguminous plants have a pleasant smell. Earthworms can often be found in the surrounding area.

Stefan Weller, advisor Bioland

Only loose soil allows for good root penetration. When taproots, e.g. of rapeseed, broad beans or sugar beet, are splitting and branching out, this is an indicator of a compaction or disruptive layer. Waterlogging and rot can also be detected at the roots.

2.2 Observation with the help of instruments

The spade test

The spade test (also called spade diagnosis) is an approved manual method for assessing the soil structure. Before cultivation, the spade test allows the depth of soil tilth to be checked. If plant growth is worse in a dry year, the weather is quickly made the culprit. But could it not also be that the root depth was being limited by a disruptive layer?

During the summer months, the conditions after sowing, as well as the effects of soil cultivation, can also be determined on the basis of crop plants. Extraction is made in four steps. In addition to the square-end spade, a small claw is needed for uncovering roots.

Step 1: Choose a test location representative in terms of growth and surface. You need to take 2 to 3 test samples.

Step 2: Choose the cut of the spade in such a manner that a crop plant is drawn during pull-out. In order to ease the extraction of the soil brick, dig a lateral hole up to the whole length of the spade's blade.

Step 3: Then uncover the narrow sides of the test sample in a wedge-shape with cuts of the spade.

Step 4: Now cut off the soil brick at the back and carefully lift out the test sample. Resting the sample on a waist-high support will facilitate the assessment.

Note: Photographs and notes of the soil surface taken before the sampling and of each test sample allow for a better assessment of the development of the soils.

Taking spade tests requires a lot of care. The soil brick should not be damaged during digging. During lift-out, the soil brick needs to be held, to prevent it from breaking apart.

Consider the following during examination:

Can you detect the desirable round soil crumbs and earthworm holes on the soil surface?

Between 'horizon A', where cultivation takes place, and 'horizon B', the uncultivated subsoil, is there a compacted middle layer, or a disruptive ploughing sole? See the boundary at a depth of 10 cm on the picture above.

Are the breaking edges in the topsoil rather round, or sharp? Sharp breaking edges indicate that the soil has had to deal with strong forces, e.g. heavy weights, and/or that the soil composition has an inferior soil-life development. Picture on the right: Round soil crumbs under the catch crop of mustard show good biological engineering.

What form do carefully uncovered roots have? Are fine and side roots abundant? Does the root length correspond to the season? Do the roots stand out of the soil brick's bottom (which would be a good sign)?

Spade test: Example of an assessment

The spade test shown was taken under winter spelt wheat. The farm had been cultivating its soils without a plough for a number of years.

The soil surface cannot be made out here, but the crumb structure in the upper part can be indicative for the soil surface. The latter was fine at the time.

You can spot the horizons rather well. Just about in the middle of the soil brick is where cultivation ends. Here you can also see working depth before the sowing of spelt wheat, at about 15 cm depth.

The soil structure of the cultivation horizon is excellent. Small round crumbs can be seen, and the spelt is able to root through this part of the soil – the many roots and fine roots indicate this. The soil also crumbles away easily. Thus it is assessed to be 'good' or 'very good'.

The nearer we get to the boundary with the uncultivated subsoil, the bigger and more sharp-edged the soil lumps are getting. Roots become visible and protrude at the lower end of the brick.

The spelt wheat is able to root through this soil. Its dense structure can also be interpreted as natural carrying capacity under ploughless cultivation. We may rate this soil condition as 'satisfactory' to 'good'.

The boundary between cultivated and uncultivated soil is very visible. What matters here is that the roots are continuing to grow regularly and that rainwater is not being accumulated (earthworm tunnels). Harmful compaction and natural, dense structure in the deeper layers are – especially if the soil is still permeable for roots – often barely distinguishable without knowing the conditions of cultivation. In this case, the examination with a soil probe alone is not helpful.

The spelt's position in crop rotation is yet to be included in the assessment. As the first crop after grass-clover, this sample would be harder to categorise. Being a second or third crop (including the cultivation of catch crop), the overall impression of the sample is good.

Stefan Weller, advisor Bioland

The soil probe (penetrometer)

The soil probe is an iron bar that sometimes comes with a pressure-measurement spring and a pressure display. The probe measures the penetration resistance of the soil, i.e. usually its density. The probe bar is pressed into the soil with a constant pressure. If the resistance of the soil grows stronger, a compaction (or a stone) must have been hit. The depth is displayed on the probe, or can be measured with a yardstick. The measurement should be performed several times. The soil probe falls short of offering data as to how the soil looks inside. If you suspect there to be difficulties, you should also dig up the soil.

pH meter

The pH level indicates the 'acid/base condition' of the soil. It has a significant effect on the plant availability of the nutrients, as well as on the soil life.

The Hellige pH-Meter is a good choice for measuring pH. Readings should not only be made on the soil surface. It is recommended to know the pH values also at the depths of 10 and 20 cm. The pH can vary significantly between different soil layers. Fertiliser input, rock dusts and limings influence the pH.

Stefan Weller

» **The spade test is a simple yet very informative way to assess the soil's condition in the field on your own. The spade test has given me a much better understanding of the soil.**

Georg Doppler, organic farmer in Waizenkirchen, Upper Austria

The Hellige pH-Meter combines the soil with an indicator solution, and the level is shown on a colour scale.

Part 3: Preserving and Improving Soil Fertility

3.1 Humus (soil organic matter) management

In organic farming, the formation of soil organic matter is regarded as an important contributing factor for the improvement of soil problems. There are good reasons for this, since a closer look reveals organic matter to be the crucial point of soil fertility:

- Organic matter tends to deposit itself as layer on the surfaces of crumbs. On such surfaces, bigger lumps tend to break again (predetermined break points), so that smaller crumbs remain. Organic matter covers the crumbs and protects them from too much water. This way, the crumbs burst less frequently in the rain, and the soil experiences less capping/siltation.
- On surfaces rich in organic matter, crumbs of heavier soils do not stick together as much. Thus soils remain cultivable over a greater humidity range. Organic matter not only lightens heavy soils, but also makes light soils more cohesive with clay-humus-complexes!

Green waste and manure become 'organic matter-like', and therefore more valuable for the preservation of soil fertility.

> **Do we take our time to appreciate soil and plant with all senses, and not just superficially when driving over it? Are we developing a sense for our soils and plants, instead of following general recipes? Have we preserved our curiosity and willingness to learn in order to better understand the complex system that is soil?**
>
> *Nikola Patzel*

- In crumbled, non-capped/non-silted soils, smaller quantities of fine material are washed into the deeper soil layers. Rain seepage also follows more rapidly. Therefore less erosion happens. Roots can intrude deeper into such soils, and get the water in the lower layers during droughts. Such soils show a better water balance.
- More organic matter means also more nourishment for bacteria, fungi and other organisms in the soil. More active soil microorganisms also reduce pest populations in the soil.
- Green vegetation decays rapidly into nutritious organic matter which is nourishment for the soil organisms. Lignified plant materials and dead microorganisms, on the other hand, take longer to decay. They integrate with clay minerals and become a clay-humus complex, i.e. permanent organic matter.
- Whether soils are rich or poor in organic matter depends also very much on the location conditions. Heavy and humid soils tend to be richer in organic matter, whereas sandy and loess soils tend to be rather poor in organic matter. The effects of organic matter reduction due to unsustainable crop rotation can often only be seen after a number of years. The formation of organic matter with crop rotation therefore also takes several years. The addition of green and manure compost can speed up the process. In this way, a lack of organic matter in the crop rotation may be partially compensated for. Additionally bought high-quality manure composts come at a price, of course.
- An increase of the organic matter content leads to a more active and crumbly soil with a better nitrogen supply. A decrease of the organic matter content leads to a tougher, quickly eroding soil with a tendency to compact and with a lower nitrogen supply.

How can one improve the humus content of the soil?

- With green and manure compost, more mature organic matter compounds are introduced to the soil, largely resisting decomposition, and promoting organic matter formation.
- Lignified crop residues are only slowly degraded, and thus tend to promote lignin-degrading, slow-growing soil fungi, which enrich the soil flora. These crop residues contribute to the formation of permanent organic matter.
- Perennial grass-clover in the crop rotation not only introduces organic matter formation, but also a lot of easily degradable root mass to the soil, and thus primarily provides nutrients for earthworms and microorganisms.

Balancing organic matter

The objective of every cultivation should be to achieve an at least balanced humus (organic matter) budget on all the plots over the period of the entire crop rotation. Whether the goal has been achieved or not can be monitored with an organic matter balance.

The methods of balancing organic matter (so far mainly used in Germany, Austria and Switzerland) are mostly built on estimates and calculations based on the crop rotation and the cultivation. For the balancing on organic farms, only a handful of methods are suitable, such as e.g. the REPRO method by Hülsbergen [1] and the site specific method (Standortangepasste Methode) by Kolbe. For the application of organic matter balances national standards apply. Organic matter balances of different farms must be compared with caution. Additionally, organic matter measurements are recommended every couple of years. However, not only the total quantity of organic matter is important, but also the quality of permanent organic matter, as well as the turnover of nutrient organic matter.

Alfred Berner

3.2 Organic matter-preserving crop rotations

A too one-sided orientation of the market in organic farming has the result that crop rotation rules are partially disregarded because of short-term aspects: crop rotations are being narrowed and lined up lacking balance, and the share of grass-clover is being reduced. When it comes to crop rotation in organic farming, the soil should again be the focus of consideration. Cultivating solely commercial crops with the highest contribution margin per hectare, and largely renouncing the cultivation of fertility building leys and green manures, will ultimately cause great problems with soil fertility and plant diseases. A good crop rotation must produce permanent organic matter in the long term, or at least keep the balance even and avoid the development of diseases, pests and weeds.

The central element of each organic crop rotation is grass-clover. Under grass-clover, the soil can rest. Weed seeds are prevented from germinating, and diseases and pests are subdued and cut down by the increased activity of soil organisms. The longer grass-clover is permitted to stand, the higher is its value as a preceding crop. Three-year-old clover meadows also effectively suppress thistles. The use of other short-term green manures however, can only partially replace grass-clover, because of their short cultivation period.

In the long run, a broad and varied crop rotation with a high percentage of green cover and changing cultivation and harvest periods will pay off.

Hansueli Dierauer

Grass-clover is an effective self-enforcer of soil fertility. Without leguminous leys or green manures as a main crop in crop rotation, durably profitable organic farming is not possible.

With regulated organic matter management, we are able to preserve the fertility of our soils and to regenerate unsound soils. The contributing factors should be made up of manure and compost fertilisation in combination with green compost and cultivation of leguminous crops, with appropriate cultivation.

Peter Neessen, organic farmer on the Terrenhof in St. Vith, Belgium

[1] *Brock, C., Hoyer,U., Leithold, G., Hülsbergen, K.-J., 2008. A New Approach to Humus Balancing in Organic Farming, 16th IFOAM Organic World Congress, Modena, Italy, June 16–20, 2008 (archived at http://orgprints.org/view/projects/conference.html).*

Crop residues of a few crop plants	
Crop	Crop residue (tonnes of dry matter per ha and year)
Potatoes, sugar beet	0,6 – 1
Autumn temporary fodder cultivation	0,9 – 1,8
Cereals, thresher peas, maize, rapeseed, field beans	1 – 2
Winter temporary fodder cultivation	1,5 – 3
Sowing for use in autumn	2 – 4
Grass-clover- and -lucerne mixtures	3 – 6,5

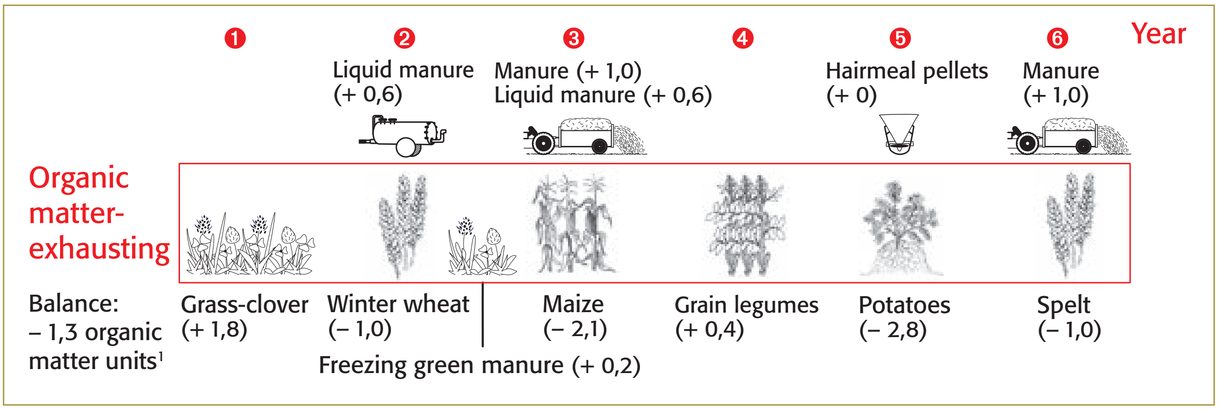
Source: Lehrmittel Bodenkunde, edition-lmz, Switzerland

Organic matter-effective rules for crop rotation:

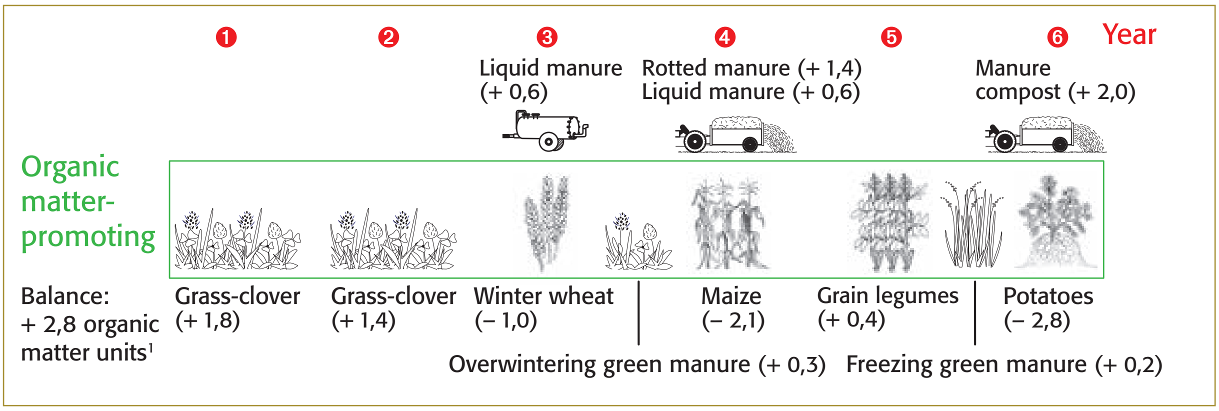
- A minimum of 20 % of grass-clover in the crop rotation, for the development of soil fertility and weed suppression.
- Maximum 60 % cereals in the crop rotation, and maximum 20 % of a single type of crop, in order to avoid diseases.
- Changing between foliage plants and cereals, organic matter-promoting and organic matter-exhausting crops, winter and summer crops, early sowings and late sowings, to prevent overexploitation of the soil, and problems with soil-borne diseases and problematic weeds.
- Cultivating catch crops for green manuring for the production of nutrients and organic matter, as well as for the protection of the soil from erosion.

Schematic examples of a organic matter-promoting and of an organic matter-exhausting crop rotation

Especially root-crop-dominated crop rotations often show a negative humus balance in practice. The following examples show how even crop rotations with strongly exhaustive root crops and an average of 0,5 to 0,8 livestock units can achieve a positive humus balance.



Organic matter-exhausting crop rotation: This crop rotation only makes use of stacked manure (muck heap) and has only single-year grass-clover. As manure is needed for maize and spelt, the farmer has to use organic commercial fertiliser for potatoes. In combination with a single frost-kill green manure (e.g. mustard), organic matter is depleted because of the root crops.



Organic matter-promoting crop rotation: This crop rotation comprises two years of grass-clover which contributes significantly to the formation of organic matter. Adding rotted manure and manure compost brings much stable organic matter into the soil. The two green manures (e.g. grass-clover, green oats) provide much fresh biomass. Despite two very exhausting crops (potatoes are simply an example), the organic matter balance of this crop rotation is positive. Farms lacking animal manure may improve their organic matter balance with generous additions of plant-based compost.

** Calculation basis: Organic matter units simplified according to Leithold and Hülsbergen, Journal Ökologie & Landbau, Edition 105, 1/1998, pages 32–35. Assumption: Addition of liquid manure: 30 m³; diluted 1:1; Addition of manure: 20 t.*

Long-straw varieties serve not only high straw production, but also the production of organic matter.

The challenge of soil fatigue

If a plant species or a group of species cannot be successfully cultivated in a soil after three to four years of cultivation break, the phenomenon is called soil fatigue. Apple trees, roses and leguminous plants are especially known for this. Soil fatigue may be caused by an accumulation of pathogenic microbes, by a one-sided impoverishment of the soils regarding essential nutrients, by toxins exuded by plants (allelopathy), by a bad soil structure, or by a combination of these factors.

Legume fatigue can pose problems to an organic farm. It manifests itself in a year-by-year decrease in the vigour of grass-clover and grain legumes. It is based on an ecological imbalance in the soil (development of pests) and various possible causes are currently being researched. A cure is usually individual to the farm and requires competent consultation.

> » Long-term experience shows that a crop rotation with two years of grass-clover does not guarantee that the organic matter content will be preserved, even less so for a soil with a high level of organic matter. It can be decisive how many crop residues remain in the field or are restored.
>
> *Alfred Berner, FiBL*

3.3 Organic fertiliser

Manure and liquid manure from animal husbandry, as well as composts and green cuttings from plant cultivation, are the most important organic fertilisers in organic farming. More recently, fermentation substrates from biogas plants have also been coming into use more frequently.

These organic fertilisers influence the soil with differing qualities: physically from liquid to firmly structured, chemically from simple-mineral to complex-organic, organically from one-sided to many-sided.

Compost

Compost contains organic matter, stabilised by rotting, which serves the production of organic matter. It provides the soil with a phosphorus-emphasised nutrient-mix. Time and again, studies have shown that compost advances soil life and soil fertility one step further than other organic fertilisers would on their own: compost rebuilds the soil. While manure compost also displays a good nitrogen effect, green waste compost has rather little effect.

In practice, the communal composting of community green waste and individual manure has proven effective, also economically; the costs of a turning machine and labour can be paid for with the contributions from green waste composting. Each country has its own legal framework to be followed.

When young, lignin-containing plant composts are added to rapidly growing crops, it may lead to a temporary nitrogen-block in the soil, especially in spring. In such cases, more mature composts already containing nitrate are more suitable. An auxiliary fertilisation with a readily available organic source of nitrogen, such as liquid manure, can help lower the risk.

Producing a (micro-) biologically high-quality compost, which does not damage the environment and boosts plants, necessitates good knowledge and experience.

What needs to be considered when composting green waste or manure?

- Compost should not be waterlogged (check by squeezing it in your fist). Covering may be needed.
- Compost should not dry out. If necessary, water the compost during turning.
- Turning the compost helps the rotting process.
- Adding soil (10 %) promotes stable organic matter compounds.
- A rotting temperature of at least 50 °C promotes hygiene and kills off weed seeds.

Liquid manure

Liquid manure contains much readily available ammoniacal nitrogen and quickly mineralising organic substances which contribute little to the formation of organic matter. The quick and specifically applicable fertilising ability of liquid manure during growth is its great advantage.

Liquid manure should be applied during humid weather on absorbent soils, in order to minimise loss of nutrients as well as the harmful effect on air and water. If too much liquid manure is applied to the soil, the emerging ammonia can burn earthworms living on the surface. A well-developed soil life may however incorporate moderate administrations of diluted or processed liquid manure of about 25 m^3 per hectare into the food chain, and thus return it into the organic cycle.

Manure

Manure, being a mixture of plant and animal substances, is a more balanced fertiliser than liquid manure. Its quality however depends greatly on its storage. For the production of soil and for yield, slightly rotted manure and mature manure compost are significantly better than fresh manure or (rotting) stacked manure. Even if only considering nitrogen, processed manure works as a better fertiliser, as it will not induce nitrogen-blocks from barely rotted straw or cause damage via manure clods. Manure compost approaches the quality of compost given a longer storage time. Deep litter manure is a special case: it usually requires an additional mechanical loosening before it can rot and then be applied.

Appropriately evaluating the nitrogen effect

The effectiveness of a fertiliser as a provider of nitrogen depends not only on its nitrogen content, but also on the ratio of carbon and nitrogen (C/N ratio). Liquid manure has e. g. C/N 7 ('narrow'), straw has C/N 50 to 100 ('broad'), compost is often around a C/N of 20 to 30. A rapid N-fertilisation takes place at a C/N ratio of about 10. With a rising C/N ratio, organic fertilisers function more and more as long-term fertilisers with an increasing contribution to the formation of organic matter. The speed of nitrogen absorption also depends strongly on general availability of nitrogen in the soil, e. g. on the nitrogen found in root exudates of legumes, on the temperature and humidity of the soil, as well as on the diversity and vitality of the soil life.

» **Manure should reach the soil as brown rotted manure or manure compost, and not as fresh farmyard manure. This way, it is best transformed by soil organisms.**

Alfred Berner, FiBL

Within the substance cycle of soil fertility, cows usually play the leading role. Digestion, milk and manure of a cow feeding on diversified roughage differ quantifiably from a heavily protein-fed cow.

Digestates as fertilisers?

Since the invention of biogas plants, it has been possible to fertilise with their digestates. The digestate often originates from the same initial substrates as compost (liquid manure, solid manure, plant material, etc.), and it also contains a similar amount of nutrients and organic matter. Due to different degradation processes during composting and fermentation, the quality of such fertilisers however varies considerably: compost emerges with oxygen from aerobic rotting; its organic matter and nitrogen are stabilised during maturation. Digestate, on the other hand, emerges without oxygen from anaerobic fermentation (rotting), and is still in the process of degradation when being applied. This is why the following should be considered for fertilisation with digestates:

- Liquid digestate (digestate/fermentation liquid manure) contains much ammonium (NH_4^+), which can easily escape as ammonia (NH_3) during drying. Digestate liquid manure should therefore be used on absorbent soil during cool, humid and windless weather – with a trailing hose or shoe, or with the slotted-nozzle procedure, perhaps even in diluted form. Avoid anaerobic conditions for formation of nitrous oxide (N_2O)!
- Moist, solid digestate can be effective as a fast nutrient provider, but makes an uncertain contribution to long-term organic matter production and adds next to nothing to the soil structure. If digestate dries out, ammonia is lost! Moist digestate may be rotted later on, to create better compost. In order to minimise loss of ammonia, you should mix in slightly rotted woody material.

In organic farming, fertilising with digestates is only allowed with restrictions (consult the relevant certification guidelines!).

Alfred Berner and Jacques Fuchs

Solid digestates can transform into more valuable fertiliser with the help of aerobic post-rotting.

Content of main nutrients (in kg per t) in organic fertilisers (fresh substance)

	C_{org}	$N_{organic}$	$N_{mineral}$	P	K
Animal-run manure*	175	4,0	1,3	1,0	9,0
Stacked manure*	150	4,1	0,8	1,4	5,5
Manure compost*	106	4,6	1,0	2,0	6,6
Green waste compost	214	6,7	0,3	0,1	4,2
Solid digestate	235	5,7	0,3	0,1	4,2
Slurry 1:1*	35	0,9	1,2	0,4	6,6
Liquid digestate	61	2,0	2,0	0,9	3,3

* Farm fertiliser from dairy cattle *Source: GRUDAF, Switzerland, 2009*

Organic nitrogen becomes plant-available in the mid- and long-term; mineral nitrogen however can quickly be absorbed by the plants and microorganisms with potential negative impacts on plant health and product quality. It is also promptly lost. The table shows average figures. Especially the phosphorus content of the fertilisers can vary widely, depending on what the animals were fed.

Is there a phosphorus-deficiency problem on organic farms?

In farms lacking addition of nutrients, phosphorus can become scarce in fodder or fertiliser. A possible way to address phosphorus deficiency without having to acquire raw phosphate would be to add manure or compost. Cultivation of legumes and the promotion of soil-microorganism activity may be able to mobilise larger quantities of phosphorus bound in the soil. Farms which are suffering from a phosphorus deficiency for plants and animals often have a high pH value in their soils. The high pH value impedes the plants' uptake of phosphorus.

» If soils have been depleted and exhausted over centuries, we have the duty and debt as arable farmers to help these soils regenerate.

Sepp Braun, organic farmer in Freising, Germany

3.4 Green manure

Good reasons for the use of green manures are manifold. They improve soil quality, decrease crop-rotation diseases, and help to bind nutrients from the air or to mobilise them in the soil. Green manuring is a one of the most important possibilities for farms with few or no cattle to nourish the soil and to produce organic matter.

But no green manure can meet all demands and wishes at the same time. Depending on what is to be achieved with green manure, different single seeds and mixtures are worth considering. A mixture with grasses is often sensible when the green manure is also being used for fodder. For pure green manures, grass-free mixtures are also well suited.

In spite of time, labour and cost efforts, the cultivation of green manures across the whole crop rotation is economically sound, as market crops deliver more stable yields.

Choose the appropriate plants for your objective

Objective: Improved soil structure, production of organic matter

For organic matter production, grass-clover mixtures with cultivation duration of at least 1,5 years are best suited, as they grow roots through the soil most thoroughly and intensively.

Ideally, the mixture is regularly mown (perhaps with fodder sales), and the last growth processed into mulch. Cattle-free farms can dispense with grasses (lucerne-clover mixtures), to bring in more nitrogen but it is usually an advantage to include grasses, as they greatly promote organic matter production thanks to their stronger soil rooting and they provide a more stable release of nitrogen with lower risk of leaching. In dry locations, lucerne-grass mixtures work best.

Objective: Erosion protection during winter

For erosion protection, the timely seeding of a winter-hardy green manure, such as a grass-clover mixture or ryegrass after cereals, or forage rye (also vetch rye) or winter turnips after potatoes or maize can be used.

Green manures and climate

Green manures that are incorporated after they have been killed by frost, or those that are rich in biomass and winter-hardy, can release more climate-damaging gases (especially nitrous oxide) into the atmosphere during freezing and thawing cycles in winter. Winter-hardy green manures sown before the beginning of September (depending on climatic region) should be mown in October, and the mowings removed from the field, e.g. for use as silage.

Objective: Nitrogen supply for following crop

The best nitrogen supplies are achieved by legume crops, e.g. peas or field beans, or, for longer service times and seeding after cereal harvesting, clover-lucerne mixtures. Dense legume cultivations, left standing until flowering, can furnish 70–140 kg nitrogen per hectare for the following crop. For short-term greening during the season and with a growth period of about 3 months, summer vetches or Egyptian-Persian clover are suitable. Undersown grass-clover stubbles bring an increase of 50 kg N per hectare.

Especially grain legumes, such as the lupine, are able to tap phosphorus for following crops, as well as fixing nitrogen.

Objective: Conservation of nitrogen for the following crop

For this purpose, fast growing varieties, especially green oats, forage rye, or mustard and *Brassica rapa*/turnip varieties are most suitable.

Oil (fodder) radish in particular can exploit deep soil layers and recuperate translocated nitrogen. If however frost-kill varieties are not ploughed before winter, and the following crop is cultivated before winter, much nitrogen can be wasted.

Quite a few new varieties are currently being introduced into cultivation as catch crops, such as Sudangrass, lyme grass, Guizotia (*Guizotia abyssinica*/ramtil), which grow fast and efficiently suppress weeds , and are in part drought-resistant. Experience will tell which ones will prevail.

Nitrogen gain from legumes

At the cut from grass-clover and pure legume cultivation, the N supply can be estimated as follows:

- Grass-clover stubbles: +50 kg N/ha.
- Grass-clover before grass shoots: 15–25 kg N/ha for each kg/m² of fresh mass. This gives us, given 1–4 kg of fresh mass per m², about 20–100 kg N per hectare.
- Grass-clover after grass shoots (including forage rye, green oats): 0–20 kg N/ha, regardless of quantity, as the C/N ratio is usually quite wide.
- Pure legumes before flowering about 30–35 kg N/ha per kg of fresh mass and m². Dense, knee-high cultivation about 3–4 kg/m² = 80–140 kg N/ha.

This silty soil of an organically cultivated vegetable farm near Vienna shows structure problems. Marchfeld has almost no animal husbandry, and therefore no farm manure. With additionally bought straw and green manure, the farm is now offering more nourishment to soil organisms, in order to improve the soil structure. This will also reduce water and wind erosion.

Green manures and their effect

Green manure/ mixture	Production of organic matter	Gain of nitrogen for following crop	Subsoil loosening	Erosion protection during winter	Prevention of pests and diseases [1]	Weed suppression	Comments
Grass-clover 1,5 years	●●●○	●●●○	●●○○	●●●●	●○○○	●●●○	Suppresses thistles and bindweed, promotes docks/sorrels. Risk of wireworms for following crop. Thorough rooting of the deeper soil with lucernes.
Pure grass seeds (up to 9 months)	●●●○	●○○○	●●○○	●●●○	●●●○	●●●○	Non-host for root-knot nematodes and many crop-rotation diseases of root crops and vegetables.
Clover-lucerne mixture (up to 9 months)	●●●○	●●●●	●●●○	●●●○	●○○○	●○○○	Suited as a green manure between cereals and maize, little 'depth effect' given an over-year-long cultivation. Longer periods of cultivation maybe applicable.
Lupines, field beans (until flowering)	●○○○	●●●●	●●●○	●○○○	●○○○	●○○○	Susceptible to nematode varieties, few problems with wireworms in following crop. Lupines need warmth. Rather unsuitable when legumes are part of the main crop.
Peas, vetches (until flowering)	●○○○	●●●●	●○○○	●○○○	●○○○	●●○○	Pea is less warmth-dependent, also suitable for winter cultivation. Vetches depending on type. Peas are unsuitable if the same are part of the main crop. Vetches only limitedly.
Phacelia (until flowering)	●○○○	●○○○	●○○○	●○○○	●○○○	●●●○	Not related to crop types. 'N-gain' via prevention of washing out.
Oil (fodder) radish	●○○○	●○○○	●●●○	●○○○	●●●○	●●●○	Not in a crop rotation with cruciferous plants, subsoil loosening only when cultivated for a longer period. 'N-gain' via prevention of washing out. Recovery effect depending on variety (nematodes).

Key: ○○○○ no effect; ●●●● = very strong effect; [1] Focus on diseases with a wide range of hosts, and nematodes

Objective: Subsoil loosening
For this purpose, oil (fodder) radish or perennially cultivated lucerne are worth considering.

The soil must be loosened with a cultivator beforehand, so that the roots and green-manure plants may access the deeper soil layers more easily and subsequently stabilise the pores (biological engineering). Oil radish also requires a sufficiently long cultivation period of at least 3 months for good effects. Lupines and field beans can, alongside other deep-rooting legumes, also be used for a deeper root penetration of the soil.

Objective: Prevention of diseases and pests
Green manures are supposed to minimise the disease and pest pressure for the following crop. Therefore no green manure should be cultivated that is closely related to the main crop (e.g. mustard with rapeseed or cabbage varieties). Peas are most succession-sensitive, followed by other types of legumes. Green manures of grain legumes do not belong in a crop rotation which cultivates the same legume as a main crop.

One should pay attention to diseases and pests which affect many different host plants, such as Sclerotinia, Rhizoctonia and certain kinds of nematodes.

Highly disease-susceptible green manures (e.g. sunflowers to Sclerotinia) should be avoided if susceptible main crops are cultivated (rapeseed, vegetables, sunflowers).

With the overwintering cultivation of a green manure, crop-rotation problems can be bypassed. For example, root-knot nematodes cannot reproduce on winter peas or vetches if the plants are broken up at an early enough stage.

Objective: Weed suppression
Seed-propagated weeds can be suppressed with fast-growing green manures. Often the best mixtures to use are ones that take well to cutting, i.e. are amenable to a cut (a 'scarifying cut') soon after growth to 10–15 cm in height, and which then form a densely closed stand. Perennial weeds, such as thistles and bindweeds, are best suppressed with perennial stands of grass-clover.

Martin Koller

3.5 Promoting wild plants instead of fighting weeds?

Most wild plants originate from riverbanks and locations where the soil was constantly in motion. Thanks to cereal cultivation they have made their way to Central Europe, where they colonised the fields as 'weeds'. They took their time adapting to certain light and soil conditions. This is why they are often specialised, some making use of even extreme conditions such as compacted soils. Europe counts about 650 plant species among its field plants. Depending on the soil's acidity and the cultivated crop (cereal or root crop), different plant communities emerge.

This beautiful cornflower brings beneficial organisms into field and vegetable cultivations. It is contributing to the agroecosystem's self-regulation.

Due to the use of herbicides, intensive nitrogen-fertilisation, seed cleaning, sophisticated cultivation techniques, and productive arable crop plants, life conditions of these field plants have worsened considerably. Today, 40 % (Germany) to 80 % (Switzerland) of those species are on the 'Red List'. Moreover, after years of conventional farming, the seed stock is depleted in such a way that the absence of location-typical species persists even years after a transition.

» **All that sprouts from the earth has its particular intended purpose, and diligently contributes to the completion of the entire Creation. Nothing growing from the earth is in vain, nothing useless … oftentimes the same that poses harm to you is harmless feed to birds and animals.**

Ambrose, Bishop of Milan, 339-397 AD

How to promote endangered field plants?

The following measures can help preserve endangered field plants:

- Minimum tillage of the soil.
- Allow for regular fallow periods.
- Choose greater row distances or sow crops by hand.
- Later on, stubble cultivation with use as sheep or cattle pasture.
- Include location-specific, older crop plants such as flax, lentils, buckwheat or millet.
- Possibly cultivate perennial forage crops (there is however a conflict of objective with soil fertility!).

This accompanying flora for oats, consisting of Camelina (false flax) and low-growing clover, will not become 'weeds'. Other wild plants like the creeping thistle, wild rye (wheatgrass) or the field bindweed should however be regulated in organic farming.

Various benefits – not least for the soil

Field plants form the basis of existence for many a beneficial organism, promote pollination rates, and provide distraction feed for pests. They also promote the soil's tilth (optimum soil condition), as they root through the crop plants and protect them from direct sunlight. On fields staying without plant cover for longer periods, such as e.g. maize, they can counteract erosion.

From wild plant to problem weed

In principle, wild plants are competitors of crop plants for water, nutrients, light and space, and were therefore exterminated for the sake of crops. The varieties permanently established in the field have adapted to weed control. Yet many wild plants are non-problematic because of their weak competitiveness.

Unfavourable growing conditions, especially, bring out varieties which are superior in growth to arable crops. Plants like the creeping thistle, the field bindweed, docks (sorrels) or wild rye (wheatgrass), which can multiply fast from roots or rhizomes, are a great challenge in the field.

A balanced crop rotation, careful soil cultivation, and optimal starting and growth conditions for arable crops often contribute to the wild plants becoming an accompanying flora which can have overall positive effects on soil fertility and harvests.

Soil cultivation irritates wild plants!

Every kind of soil movement, even that provoked by a light, minimal tillage of the soil, stimulates the wild plants' germination. If there is a strong emergence of wild plants, these can be controlled with multiple minimum stubble-tillage or multiphase seedbed preparation with a pseudo-seedbed. Only after these possibilities have been tried should one decide whether weeds should be controlled with special devices or in other ways.

Lukas Pfiffner and Herwart Böhm

How many field plants does wheat tolerate or need?

» Many studies have substantiated the important role organic arable farming has in protecting endangered field flora. In organic fields, the diversity of wild plant varieties is two to three times higher than with herbicidal cultivation. High cultivation intensity, nurse crops, perennial field forage-crop cultivation, excessive control of field weeds, and immediate stubble cultivation have adverse effects on the diversity of the flora in organic farming too.

Lukas Pfiffner, FiBL

3.6 Soil compaction and how to avoid it

Soil compaction – Machine-induced damage on the ground

Soil compaction occurs when vehicle-induced soil pressures are higher than a soil's carrying capacity. Any soil can be compacted, be it sandy or clay soil. Damaging compactions of clay soils are quickly apparent. Fertile loess-loam soils seem to be more forgiving of mistakes. But even they show compaction, although yield reductions may only be seen in years of extreme weather conditions. Even small proportions of silt and clay increase the compaction sensitivity of sandy soils.

A severely compacted soil, with mechanically loosened subsoil, before the sowing of lucerne.

Growth of grass-clover and lucerne with unhindered soil penetration of over 2 metres depth.

What to do if soil is compacted?

During mechanical loosening of the subsoil, the soil may lose more of its structure, resulting in a re-consolidation worse than the original compaction that was being tackled. To avoid this, the following should be observed:

- Only carry out subsoil loosening if the soil is dry in the loosening depth.
- Stabilise the loosened structure by sowing long-term deep-rooting plant species (e. g. grass-clover, lucerne), if possible during the same working step.
- Change cultivation techniques in such a way that mistakes are not repeated.

If the soil is being compacted, this primarily means that the soil's supply lines for oxygen and water are being crushed. As a consequence, the soil absorbs water less well, and water drains off on the surface. The living conditions for soil microorganisms and roots deteriorate with the lack of air exchange, i. e. the resulting lack of oxygen. Soil compaction makes physically deep-reaching soils ecologically shallower by obstructing roots from growing into deeper soil layers.

"The courage of waiting is one way to avoid mistakes"

Soil moisture is the defining factor of a soil's carrying capacity because the water works as a lubricant between the soil particles. If there is too much water, the soil structure ceases to support it. It takes nerve to wait until the soil has dried and is stable, but it is well worth it in the long term. An anticipatory crop rotation and choice of crops, allowing for more flexibility especially during the sowing and harvest season, can be helpful in this case. Catch crops draw water from the soil in autumn and improve its carrying capacity for autumn sowing.

» Sometimes a soil has been so compacted with heavy machinery that life can barely get by. In this case we need to apply expensive technology and roughly repair the damage. Then, everything needs to stabilised with complete root penetration of all the soil layers, and be brought back into balance. We as humans are responsible for this.

Sepp Braun, organic farmer in Freising, Germany

» We first had to learn what a heavy soil really means. If you have got a spade and take out about a spade's length of soil, and water is present, it is quite clear that you have no business working on the soil. It may look dry on the surface, but this does not mean that you can go on the field. And you really need to develop a sense for this.

Uwe Brede, organic farmer in Hesse, Germany

Soils are more stable if they are cultivated less often and less deeply. Uncultivated soil develops, thanks to the work of earthworms and microorganisms, a thorough system of pores, which ensures sufficient air and water supplies. There may however be conflicts with mechanical weed control operations.

The inner pressure of a tyre largely corresponds to the pressure on the soil surface to a depth of about 10 cm. This makes it clear that the tyre pressure should be kept low. Modern radial tyres are ideal, as they can be driven on the field with a very low pressure, whereas trailers with truck tyres do not belong on the field!

To determine how much the tyre pressure can be lowered, one needs to find out the wheel load (measured axle load divided by two), and to read the minimal tyre pressure for the wheel load and driving speed recommended in the tyre-pressure table provided by the manufacturer. This procedure increases the transfer of traction and reduces surface-smearing slippage.

The greater the wheel load, the deeper the pressure penetrates the soil, independent of contact area and inner tyre pressure. Wide tyres can therefore help avoid topsoil compaction, but are less effective against subsoil compaction given higher wheel loads. Lighter tractors, trailers and machinery are generally more soil-conserving, and allow for inner tyre pressures of even less than 1 bar/14,5 Psi.

As an additional rule: the more frequently the soil is driven on, the more compaction you have in the driving lane. Driving practice adjusted to the requirements of the soil promotes soil fertility and saves money.

Melanie Wild, Markus Demmel, and Robert Brandhuber

The on-land plough can drive outwith the furrow. The as yet uncultivated soil sustains less damage from driving. Slippage and the creation of a plough sole can be avoided. The usual rules of practice against soil compaction still apply for the on-land plough.

This very compact silt soil on a slope is – physically – moderately compacted. Was the compaction caused by driving, or may we interpret it as a 'good natural carrying capacity for driving'? After decades of strong erosion, this soil has been cultivated without ploughing, but including the use of glyphosate. The soil is permeable for earthworms and water; erosion has been stopped. However, the dense bedding and the modest organic activity of the soil have led to a lack of mesopores as well as to a relatively low water-retention capacity.

3.7 Soil erosion and how to avoid it

Every mechanical soil cultivation technique loosens the soil's compound structure and thereby reduces the energy expenditure needed to wash away soil material. Freshly cultivated soil lacking a protective vegetation cover is, given even a very slight slope, vulnerable to the impact of raindrops and to surface runoff.

The pictures show the impact of erosion. The remaining soil is structurally weak, and shows a low germination rate. Sown-in soil from a depth of 0–20 cm (A), 20–30 cm (B), and 30–60 cm (C), under a 700-year-old meadow.

> **The primary objective of farming should be to keep the soil permanently covered. Even organic farming can still improve in this area. For instance, we should reconsider the late sowing of cereal in autumn; the soil lies bare for a long time and the cereal cannot possibly exploit the available nutrients before winter. We should further favour mixed instead of monocultures – this is where organic farming still barely differs from other cultivation methods.**
>
> *Bernd Ewald, organic advisor, IBLA, Luxemburg*

Organic farming generally creates good conditions for the prevention of water and wind erosion: The proportion of especially erosion-vulnerable row crops is low, and grass-clover guarantees a good soil cover and helps to stabilise soil aggregates after cultivation. Nevertheless there are periods without soil cover and the 'clean-wiped slate' associated with the use of the plough is still common practice.

Robert Brandhuber, Markus Demmel,and Melanie Wild

Erosion-effective cultivation measures:

- Lay out hedges transversely to the slope. The division of a 200-m-long, erosive slope into two 100-m-long slopes reduces the soil loss by a third.
- Lay out wide grass verges alongside streams as buffer zones, ideally with trees and bushes. A number of countries offer corresponding funding programmes.
- Where possible, cultivate transversely to the slope.
- Avoid the cultivation of crops with wide row spacing (e.g. maize) or requiring frequent soil cultivation (e.g. field vegetables) on erosion-endangered fields.
- Cover the soil with catch crops and nurse crops.

Requirements for erosion protection

- **In United Kingdom,** to qualify for your full Basic Payment Scheme (BPS) payment or any payments under greening or agri-environmental schemes, you must meet the requirements of GAECs 4, 5 and 6. This means that you must: a) take all reasonable steps to protect soil by having minimum soil cover unless there is an agronomic justification not to or where establishing a cover would conflict with requirements under GAEC 5 (GAEC 4); b) manage your land to minimise soil erosion (GAEC 5); and c) use appropriate practices to maintain the levels of organic matter in soil (GAEC 6).
- **Germany** implemented stricter regulations for erosion protection in erosion-endangered locations in 2010, within the scope of Cross Compliance (requirements for direct payments).
- In **Austria**, the measures 'greening of arable land' and mulch/no-till farming can be combined with organic cultivation on the same piece of land, and are eligible activities within the agri-environmental project. Similar funding measures are offered by the German federal states.
- **Switzerland** counts criteria regarding catch crops and soil-cover rate among its requirements for the 'ecological proof of performance'.
- In **Luxembourg**, the sowing of catch crops and nurse crops, mulch and no-till farming, and the planting of erosion-controlling or green verges are supported by an agri-environmental project.

A bad surface structure should be a warning signal to every conscientious farmer! A good cover and well-nourished biological engineering in the topsoil are prerequisites for a sustainable agriculture. Pictures: An arable field without (above) and with (below) organic fertilisation after heavy rain (long-term DOK-trial by FiBL in Therwil, Switzerland). An organically nourished and biologically active soil can better absorb rainwater, and retains its surface structure even after the rain. Thus, the soil is better protected against erosion.

» The worse the soil structure is, and the more energy a plant needs to root through the ground, the weaker it is. This can play a role for surface diseases and pests. What's more, the environment in the soil often promotes certain foot diseases. I observe this often with peas, which are very susceptible to compaction. If the soil is too dense, foot diseases occur more often and can be identified at an early stage. Soil structure and plant health hence often strongly correlate. Cereal varieties are mostly less vulnerable than peas.

Harald Schmidt, SÖL

Nurse crops are an effective measure against erosion. The soil-covering vegetation absorbs the impact of raindrops, and the near-surface rooting has a superior cohesion effect for the soil.

Part 4: The Future of Soil Culture

4.1 Taking account of the climate

Agriculture and climate change are strongly correlated. On the one hand, agriculture is threatened by global warming: increasing drought, and augmented extreme precipitation and erosion, pose difficulties for food production worldwide. On the other hand, agriculture contributes about 10–15% of overall greenhouse gas emissions. Taking into account the emissions of the supply industry (fertilisers, pesticides), and land reclamation through deforestation, the contribution goes up to 30%.

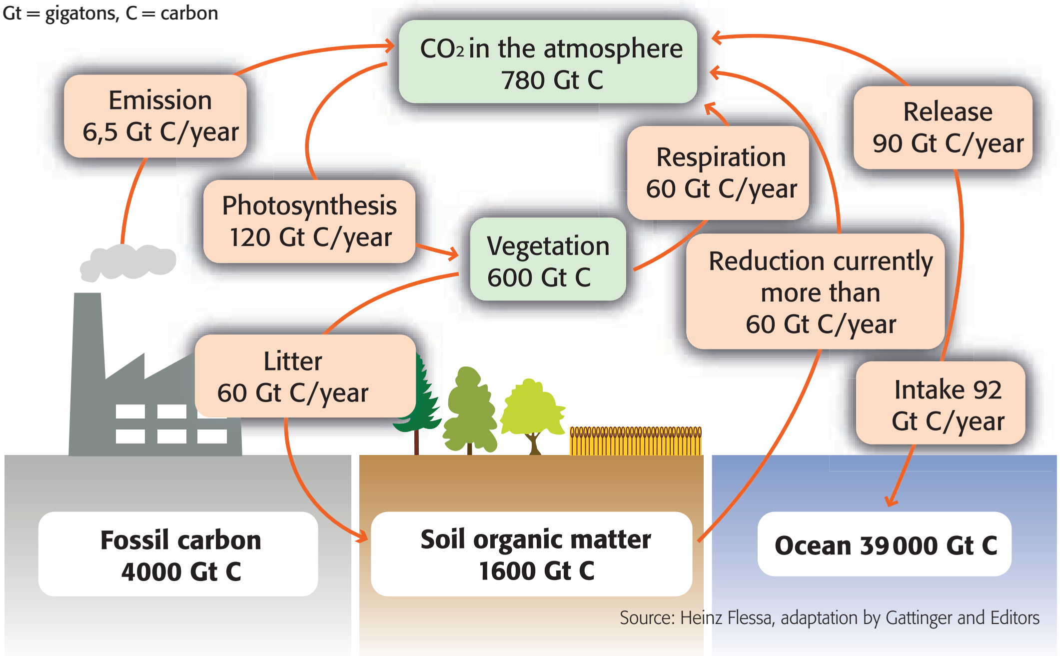
> **»** The organic matter supply is not only crucial for soil functions and yield performance. It determines the carbon storage of the soil, as well as most greenhouse-gas flows of agriculture. Our research team is developing organic matter-balance methods, in close collaboration with practice and consulting services. The objective is to shape crop rotation, fertilisation and soil cultivation in a way that gives rise to the location-specific optimal organic matter content.
>
> *Kurt-Jürgen Hülsbergen, TU München (Weihenstephan), Germany*

The importance of soils in the global carbon balance

With photosynthesis, plants form organic C compounds from atmospheric CO_2. The compounds are then released into the soil as root residues/exudates or driven off the field as harvest. The area of the soils (the pedosphere) is, after the oceans, the second largest carbon reservoir of the animate earth (the biosphere)! In the organic matter and soil life of the earth, there are about 1600 billion tonnes of carbon, which is significantly more than in the atmosphere (780 bn t C) and vegetation (600 bn t C, especially wood) combined. In the soil, the carbon from plant residues and organic fertiliser either oxidises or is converted to organic matter. Organic matter consists of about 60% carbon. With a C-content of 1% (this corresponds to a organic matter content of about 1,7%), the topsoil binds about 45 t C per hectare.

The turnover and reduction rate of organic matter varies from a few days to weeks for fresh plant material, to years or decades for straw, farmyard manure or well-rotted compost – and to centuries or millennia for highly interconnected organic matter. The more organic matter compounds are bound to each other and to clay minerals, and embedded in structurally stable soil crumbs, the more protected they are from degradation processes.

The function of soil in the carbon balance



Source: Heinz Flessa, adaptation by Gattinger and Editors

Organic matter formation and breakdown play an integral part in climate-relevant carbon flows. The CO_2 content of the atmosphere is currently increasing by 3,3 Gt C per annum. The exchange of C with lime, the greatest carbon reservoir by far, works much more slowly and thus does not appear on this diagram.

The potential of organic farming for storing carbon in soils

System comparisons worldwide have shown that organic cultivation systems are able to retain about 500 kg more C per hectare and year than comparable conventional systems. During the first ten to thirty years after conversion of cultivation, the soils store additional carbon. After this, a new balance is established. If the crop rotation is also significantly simplified in organic farming, perhaps even by doing without grass-clover cultivation in a main-crop position, the existing organic matter can definitely not be maintained. Intensive soil cultivation also stimulates organic matter reduction and further wastes a large amount of crude oil.

Comprehensive studies in Europe have shown that currently most soils have a net carbon emission into the atmosphere. One reason is that the already increased average temperatures are leading to organic matter reduction and are therefore self-reinforcing. These studies further show that in practice only a small minority of farms is actually using their potential for organic matter production!

Methane and nitrous oxide

Methane (CH_4) has a greenhouse effect 20 to 40 times as strong as CO_2. Living and well-aerated soils absorb methane from the atmosphere and break it down. This is opposed by the production of methane by farmyard manure. (Manure-) composting produces far less new methane than other farmyard manures.

Nitrous oxide (N_2O) has a 310-times greater greenhouse effect than CO_2. It occurs when there is a lack of oxygen in the soil, even for a short time. The greater the quantities and concentrations of nitrogen introduced by fertilisers, the greater the amount of nitrous oxide that is produced. Therefore high concentrations of mineral nitrogen (N_{min}) should be avoided in the soil solution, and a good natural air supply and water permeability of the soil should be ensured. Research has shown that organic fertilisers with a high ammonium-N content have an increased N_2O-loss potential. Such fertilisers, e. g. pig or biogas liquid manure, can be as damaging as ammonium-nitrate fertilisers. It is part of the high art of farming to adjust the N-entry and N-mineralisation from organic compounds according to the crop's actual need. A rather early, shallow ploughing of grass-clover with an immediate following crop helps to avoid 'undigested' plant residues after freeze-thaw cycles in winter leading to high emissions of N_2O.

Andreas Gattinger, Kurt-Jürgen Hülsbergen, Adrian Müller, Andreas Fließbach, and Hartmut Kolbe

Green soil surface tends to absorb CO_2, and brown surface to emit CO_2.

4.2 Improving the stability of the agroecosystem

Man-made climate change will lead to weather patterns changing in Europe, with increasing extremes. Organic farming can prepare accordingly, so as to achieve satisfactory harvests even in bad years.

It is mainly a question of being able to manage with much or little water. In crop cultivation, this has consequences for resistance against pests and diseases. Stability during thunderstorms, which are likely to increase with climate change, might also pose problems for some crops.

1. The most important thing in times of crisis is a very vibrant and varied soil life. A good network of soil organisms helps the plants to obtain the necessary nutrients and water even during times of scarcity, as well as to find help against disease and pest infestation in the 'immune system' of the soil-plant organism during times of weakness.
2. A permeable soil structure not only prevents lack of oxygen, but also protects against flooding, and minimises risks of water-induced surface, rill and gully erosion. Organic farming further necessitates light cultivation machines, which have a lower risk of soil compaction.

» **Mixed cultivation systems which occupy many different 'layers' in the soil and have plants of various heights make the most efficient use of the land area among agricultural food production systems. At the same time, they have the greatest utilised biodiversity.**

International Assessment of Agricultural Knowledge, Science and Technology for Development, 2009

3. A complete soil cover reduces water loss. Shrubs, such as hedges or agroforestry thwart drying winds, and the half-shade provided by shrubs or mixed cultivation can also be an advantage for certain crops (apart from rather humid conditions), as they do not need to close their breathing pores (stomata) to protect against evaporation.
4. Organic matter can store 3 to 5 times its own weight in water. With e.g. 1% more organic matter, the soil is able to store 40 mm more water for plant availability. Reduced soil cultivation improves the infiltration rate and water-retaining capacity, thanks to the increase of organic matter in the topsoil.
5. The soil must remain permeable for roots as deeply as possible, which means that one should not create barrier layers. This way, especially deep-rooting plants like lucerne, oil (fodder) radish and sunflower are able to resist dry periods.
6. Varieties bred in organic conditions must deal with more weeds and microbes than those growing under the protection of chemical agents or with artificial fertilisers. The former are therefore automatically being selected on the basis of disease resistance and the ability to prevail. A further aspect of breeding is stability.
7. Plants' resistance to dry periods depends on breeding aspects (thickness of cell wall, breathing pores, among others), but also on balanced availability of nutrients during growth. Not overdosing the soil with nutrient salts is self-evident for organic farming.
8. Mixed cultivation gives greater yield stability, as certain plants assert themselves better depending on the weather, thereby balancing out yield losses of the weaker plants. Generally, diversity can stabilise the overall yield on a farm (e.g. lucerne for dry and clover for humid conditions).

The saying "The soil is the stomach of the plant" dates back to the times of Hippocrates. Others call soil the naturally-creative 'head' of agriculture. Yet others call it the "the Bosom of Mother Earth". All these designations point to a truth.

Conclusion: The more self-supporting and stronger a certain location's soil fertility is, the better the stress tolerance and robustness (resilience) against weather extremes. Thus all recommendations of this booklet will also help secure yields in bad years. Crops and machines adapted to extreme weather are also needed to this end.

Sepp Braun; Department of Soil Sciences FiBL and extension Bioland

4.3 Ideas for the organic soil culture of the future

In its past development, organic farming has achieved on an exemplary level. Organically managed soil-plant organisms are in themselves more fertile and stable than artificially nourished and heavily technically controlled systems with minimal self-regulation.

But: The greater the surfaces cultivated with only one plant variety or few varieties in rotation, the further away the ecosystem is from the flexible balance seen in natural meadows and forests. Nature has only few monocultures, which collapse quickly. As crop farmers, we are however insisting on the former, and prevent the biodiversity moving naturally into the farmland with great expenditure of external energy: diesel for intensive mechanical control of spontaneous growth, and for the artificial restructuring of the soil. In order to be able to farm consistently differently and better adjusted to the inherent needs of soil fertility, we need visions and innovation for all players in organic farming. Here are some suggestions:

Firstly: Paying more attention to overall yields instead of individual yields

As extremely high individual yields of a cultivation crop can only be achieved with very one-sidedly optimised and highly sensitive high-maintenance varieties, we ought to bid goodbye to the industrial ideal of maximal individual yields in organic farming. Instead, we can aim at optimising the yield of the overall system, which is sufficiently robust even against weather extremes. Perhaps this will bring us mixed cultures which are simultaneously suitable for the harvesting of food, feed and energy sources – together with 'harvested services', such as climate protection, the new use of resources and the conservation of a regionally sustainable water cycle.

Secondly: More and more differentiated cooperation with soil organisms

Earthworms, mycorrhizal fungi, rhizobia bacteria, and many more soil organisms can become more valuable partners for agriculture. Our arable farming techniques should be species-appropriate to them as well.

We may improve their living conditions with purposeful agricultural practices, such as the cultivation of host plants, mixed cultures, grass-clover cultivation, preserving soil cultivation, and a selection of matching varieties. It needs to be examined whether, in special cases, it makes sense to vaccinate purposefully species-appropriate Rhizobia, Mycorrhiza fungi, and further microorganisms, such as is already a standard with Rhizobia for soya.

Thirdly: Organic farming needs other varieties
Instead of the current crop plants which cannot survive without narrowly defined conditions, we need 'socially competent' varieties which can be stable in more near-natural conditions: Perhaps long-straw cereals will find their place in the sun on their own, with much bigger ears than now, but with a lower population density? Will there be perennial varieties, a good perennial rye, perhaps in mixed culture with legume undergrowth? Or even involving caraway or parsnip… ?

Fourthly: Nature-appropriate machines
Future farming need not be technology-hostile. We can use devices and machines which serve nature and the creation – i. e. which do not combat them or run counter to the advantages of organic farming. More concretely, this could mean: Light vehicles instead of 'field tanks'? Combine harvesters collecting also weed seed, instead of blowing it onto the fields? Perhaps even, for certain activities, selective weeding and harvesting machines which find their way in a mixed culture thanks to sensors and an electronic control unit?

Fifthly: Soil culture needs education and culture
Not technology, but man is decisive for whether agriculture is sustainable or not as a culture. Fertile soil nature needs fertile human nature, and cultivated soils need cultivated humans. This is complementary to the motto: "Healthy soil – healthy plants – healthy animals and humans". Does this lead us back to more education and extension work instead of regulatory compliance and controls? Education and extension work more geared towards our values and visions, and less towards economic general conditions and regulations by the market and society? Involving more mutual exchange, life- and farm-development guidance, before suitable technological and economic advice?

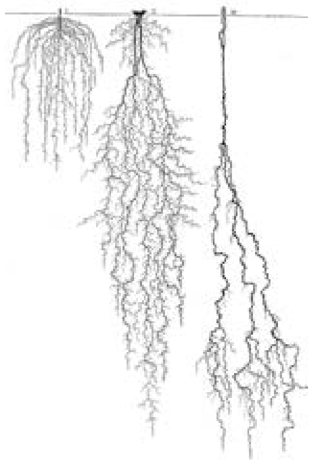
Sixthly: Sustainability needs the renewal of forces and resources
Soils and humans become exhausted when they are giving more than what they are receiving. Exploitation cannot be sustainable. Renewability also entails that we re-enhance local, regional and global cycles, and that we are open to system changes. The future will show if we will be producing faeces compost, or if we will also introduce ash and charcoal from the farm's own wood heating into the soils. What will certainly be important is that field work will only access energy sources which truly meet sustainability criteria.

Oats with Camelina is a simple example for intercropping – a method that still has much development potential.

Outlook: Visions start with the individual and lead to community
Starting from the current situation of organic farming, our agriculture still needs to achieve a great deal if it is to last for hundreds and thousands of years. Visionary courage and strength are still needed to make our agriculture truly sustainable and viable via trials and failures.

It corresponds with the nature of soil fertility, as well as with a positively creative idea of man, that the advancement of the handling of the soil cannot be achieved with tighter requirements in guidelines. To this end, it needs the freedom and development of the individual, and the exchange of ideas and help among each other.

Sepp Braun, Paul Mäder, and Nikola Patzel



Organic farming is not only a question of surface, but also of depth.

» People's demand for organic foods shows that a rethinking process is under way. Organic farming thus is increasingly corresponding to the needs of the people. A transition to organic farming provides us also with the opportunity to preserve the fertility of the earth for future generations.

Jean-Louis Colling-von Roesgen, Luxembourg

Further Information

www.agricology.co.uk/category/soil-management: A selection of the best available resources.

www.organicresearchcentre.com > IOTA > Research dissemination > Technical leaflet downloads from non IOTA research projects: Technical publications from organic research.

www.organicresearchcentre.com > Research and development > Soils and cropping systems: Information on research projects.

http://horticulture.ahdb.org.uk/great-soils: Information resources elavorated by the GREATsoils programme funded by AHDB Horticulture.

Advice

For advice related to soil fertility management in UK please contact:

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