MTK

MTK's and SLC's Soil Programme

Back to the roots – maintaining the productivity and appreciation of soil

SLC

SUMMARY

Soil provides a variety of hidden solutions for the security of supply, climate change and protecting the environment. The solutions stem from the practice of agriculture and forestry, but only if soil fertility is given a chance. The MTK-SLC soil programme uncovers the dependencies of soil properties and the possibilities of soil maintenance as a foundation for the bioeconomy, including the sustainability of the food system.

The programme includes 62 measures that agriculture and forestry operators consider essential steps in securing the productivity and purity of soil. The starting point is the UN sustainable development goals and increasing the understanding of soil functions, with MTK's climate programme, MTK's biodiversity programme, the MTK-SLC water programme and the MTK-SLC climate roadmap for agriculture in the background.

Many soil risks are attributed to industries that utilise soil growth, without any detailed analysis of the soil processing methods and their effects. This programme studies the other side of the coin and through its proposals for measures, shows how sustainable agriculture and forestry secure the vitality of soil.

The programme is a response to EU policies and emphasises the sustainable operating methods used in Finland, such as the 70-year-old fertility analysis as the basis for field fertilisation and the coverage of forest certification. A shared understanding of the condition of the soil and changes in it is based on definitions and concepts. They have been presented in figures and tables. The cornerstones of the programme are soil fertility, purity, measurement and ownership. The measures have been classified in six themes. The arrows refer to the summarised measures:

1. EFFECTIVENESS AND BALANCE OF GROWTH FACTORS

› Soil fertility is maintained and improved through the balance of the biological, physical and chemical properties of soil; in practice, through the range of species, plants that have a lot of roots, water management, avoiding soil compaction, targeted plant nutrition and by liming.

2. SOIL QUESTIONS IN AGRICULTURAL POLICY

› It is acknowledged that 1) drainage and liming investments that improve soil fertility require profitability and the security of land tenure, and 2) changing weather conditions have an impact on soil functions and cultivation, so flexibility is needed in date restrictions and tillage or plant cover requirements.

3. SOIL QUESTIONS IN FORESTRY

› The conditions for growth are safeguarded by silvicultural methods appropriate to the site, using light tillage to ensure regeneration, and with appropriate fertilization. Soil growth factors are improved by adding mixed deciduous tree species.

4. RELYING ON SOIL PURITY

› The development of the quality of fertilisers, soil improvers and pesticides is promoted to ensure that harmful substances that compromise the purity and functions of the soil are not transported with them.

5. COMPLEMENTING THE LACK OF INFORMATION WITH NEW KNOWLEDGE

› The interpretation of the soil testing, measurement of soil emissions and cycles of substances in practical agriculture and forestry, as well as the understanding of connections in plant nutrition and soil biology, are advanced.

6. LAND IN OUR CONTROL

› The protection of land ownership under the constitution and the related rights are strengthened as the basis for the appreciation and management of soil across generations.

The proposed measures secure the productivity and health of soil, while keeping the importance of the profitability of industries in mind. Decision making based on the latest information and high-quality measurements guides fairness. The soil data gap is still unacceptably large.

The protection of land property and the security of land tenure are essential prerequisites for work with our forests and fields across generations. Industries need a stable and predictable operating environment. Stability and taking care of the soil will become increasingly significant as the climate changes, and weather conditions become increasingly unforeseeable. The active maintenance of soil fertility is a driver for the future – our lifeblood, which needs to be secured. By the measures proposed as a guideline.

FOREWORD

Soil is part of the global biosphere and the foundation of renewable natural resources. Living agricultural and forest land ecosystems offer the possibility to engage in agriculture and forestry. Sustainable management of productive arable and forest land across generations promotes the security of supply, biodiversity and necessary climate solutions. Soil well-being and its fertility are a necessary element in sustainable development, in which land tenure plays an important role.

Demand for food is growing with the increase in the world's population. Forestry produces renewable wood raw material for renewable products as well as energy raw material and ecosystem services. By actively improving land productivity and the state of the environment, we can address the nation's demand for food, food exports as well as the increasing global demand for renewable raw materials.

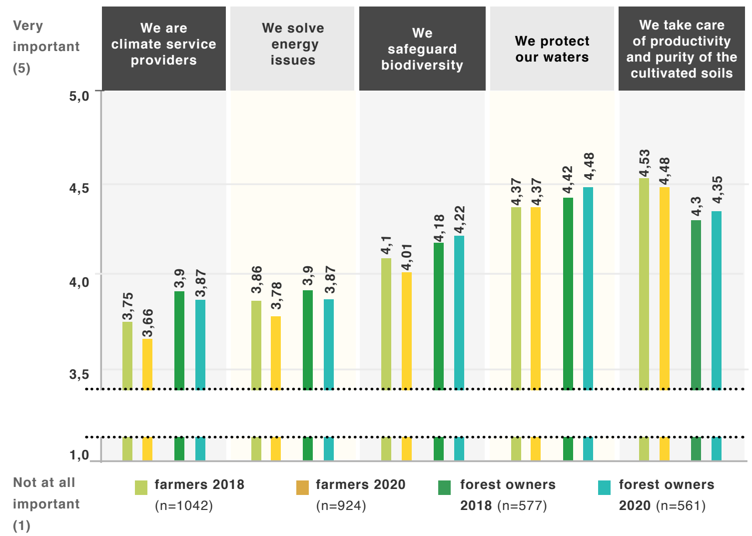
According to the Ympäristöluotain survey, which was intended for the members of the Central Union of Agricultural Producers and Forest Owners (MTK), land productivity and purity are the most important environmental promises for Finnish farmers and forest owners[1]. Poor profitability of the industry, structural development and uncertainty about land tenure make it difficult to address the mindset of soil management.

Fields and forests with different properties and their living soil are an important part of the diversity of agricultural and forest nature in Finland[2]. Our abundant water resources and regenerative forestry and cultivation methods keep the soil covered by vegetation to bind carbon from the atmosphere and contribute to the diversity of biotopes.

Productive, healthy agricultural and forest land, and especially the active maintenance of arable land, the aim of which is to ensure soil fertility in an ecologically and economically sustainable manner, are at the core of this soil programme. In practice, non-renewable soil calls for continuous maintenance to keep the soil offering its best for securing the well-being of people and nature.

Soil is an absolutely critical element for life on earth. It contains 25% of the world's biological diversity. There is approximately two times more carbon in soil and about three times more in soil vegetation than there is in the atmosphere. Approximately 95% of our food is directly or indirectly produced from soil[3].

> How important do you consider the promise in your activities? (Kantar TNS Agri Survey to MTK members 10/2028 and 5/2020).



The goal of the UN Sustainable Development Agenda 2030[4] is to

- protect, restore and promote sustainable use of terrestrial ecosystems
- promote the sustainable use of forests
- combat desertification
- halt land degradation and biodiversity loss

RISKS OF SOIL

More and more pressure is imposed on the effectiveness of soil, which requires harmonised, extensive follow-up in order to direct soil management in a sustainable manner.

Internationally recognised risks on soil include construction, acidification and contamination as well as the loss of organic matter, which is the biggest in Finland of all the EU countries[5]. However, the alarmingly high cadmium content of arable land is a soil risk that Finland has managed to avoid. Excessive salinisation of the soil is a risk elsewhere in the world, but in Finland the lack of salt reduces the retention of nutrients and solid matter which can be mitigated using soil improvement gypsum.

Finnish soil is young, having originated after the Ice Age. The properties of our arable land are currently undergoing a special change as the climate is warming. The increase of precipitation in winter and the lack of frost impair the structure and bearing capacity of the soil in Nordic conditions. Weakened soil aggregate stability increase the risk of erosion and compaction during wet periods. Drought during the growth seasons as well as prolonged heatwaves reduce plants' use of nutrients. Precision agriculture reduces the risk of over-fertilisation.

Soil risks [5–7]	Europe	Finland
Construction	400 km²/year	60 km²/year
Erosion	10-15% of land area > 5 tons/year	average 0.5 tons/year
Compaction	> 20% of subsoils compacted, 21% of subsoils contain cadmium above the risk limit	Estimate: the same
Contamination	risk limit	not in Finland

A healthy, well working soil produces more with less input and withstands pressure of change. Even though agriculture has become more efficient, the condition of agricultural land and soil fertility have impaired globally[5]. More than a half of the EU Member States, including Finland, face a risk of farmland abandonment causing negative impact on e.g. semi-natural habitats [6].

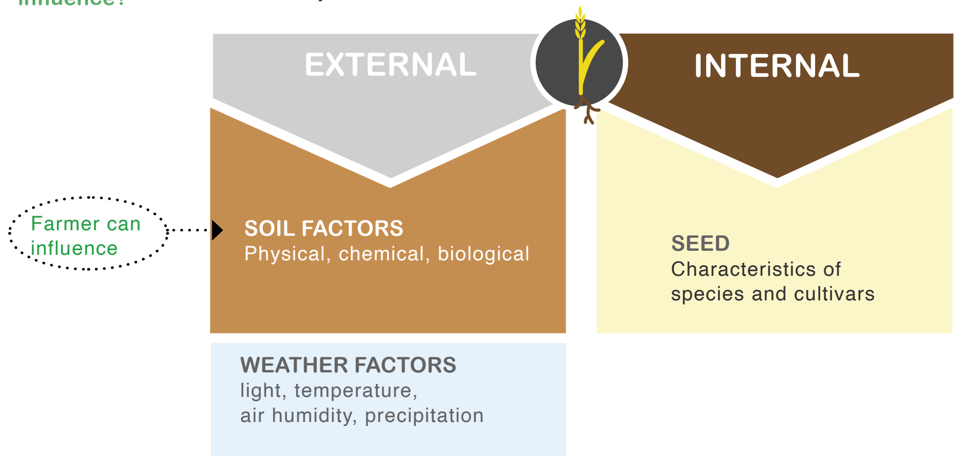
The carbon sequestration of growing vegetation is a solution to mitigate climate change and adapt to it[8]. When agricultural and forestry land is productive, some of the soil can be left temporarily uncultivated to secure broad biodiversity. This allows different forms of land use to together secure the well-being of nature and man within planetary boundaries.

- Promoting sustainable ways of improving the efficiency of cultivation that recognises soil-related risks and utilises the opportunities offered by technology so that the goals of the UN Sustainable Development Agenda 2030, the Paris Climate Agreement and the International Biodiversity Agreement can be achieved.
- Increasing understanding of the soil functions that depend on soil type or weather conditions and are controllable by man.

> Growth factors: Can we influence?

Growth factors = factors affecting plant growth

= all the impacts or materials decisive for the plant's growth; the impact can be positive or negative, depending on quantity or efficiency



EFFECTIVENESS AND BALANCE OF GROWTH FACTORS

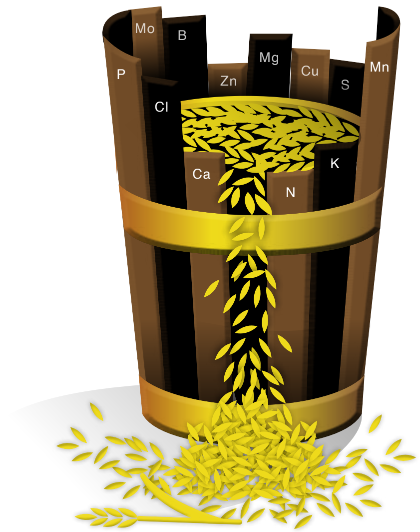
Resource efficiency involves producing more with less. In that case, growth factors must be ideal. The effectiveness of soil growth factors is based on the structure of soil and thereby on water management aeration and strength properties[9]. These physical growth factors in soil are regulated by soil ecology, i.e. organic matter in the soil and micro-organisms in the process of root system growth and decay.

In an effective soil pore system, the roots are capable of utilising chemical growth factors in soil, i.e. nutrients, which are the food for plants. Finnish soil is typically acid. As nutrients in mineral soils can be best utilised by crops in almost neutral conditions, liming that increases soil pH is necessary in order to manage and maintain the fertility of arable land. Maintenance liming is needed, as the decomposition of organic matter as well as fertilization acidify soil. In organic soils and forest soils, plants manage in more acid conditions.

Soil fertility is a whole made up of physical, biological and chemical properties and functions that ensure soil productivity. In the best case, as much high-quality biomass as possible can be obtained with as small emissions as possible. The lack or inoperability of one factor will limit the utilisation of other growth factors.[10,11]

- Recognising the whole made up of different growth factors and the interdependence of soil factors necessary for growth (law of the minimum).
- Producing food and feed efficiently on the best plots and sustaining their physical, biological and chemical fertility.
- Using plots with a poorer yield to promote natural diversity and as carbon sink grassland storing carbon and restoring fertility.
- Sustaining soil fertility by diversifying crop rotation, avoiding soil compaction, liming, ditch drainage, preventing drought and using soil improvement materials.
- Increasing plant cover and the cultivation of deep-rooting plants in crop rotation and mixed crops to avoid the loss of soil organic matter in agricultural land.
- Holding on to the ability of soil to produce good, high-quality crop yields, which reduces harmful impacts on climate and watercourses.
- Making sure that regulation concerning drainage or neglecting drainage will not compromise soil fertility and efforts to adapt to climate change.

> Minimum law concerning plant nutrients in soil.



LOST CROP
YIELD POTENTIAL

Law of the minimum concerning nutrients (Justus von Liebig 1840) describes how soil productivity is determined according to the weakest growth factor. One nutrient cannot replace another or the lack of other growth factors, such as airiness. Indicators of biological mechanisms are needed to complement chemical and physical growth factors to ensure that the functionality of the field ecosystem can be fully investigated.

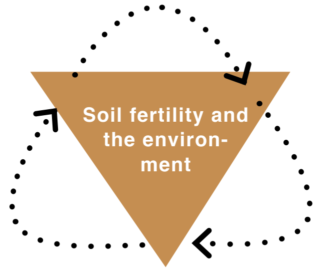
> Soil fertility areas of influence.

Biological state

micro-organisms
(fungi, bacteria)

soil fauna
(earthworms etc.)

organic matter



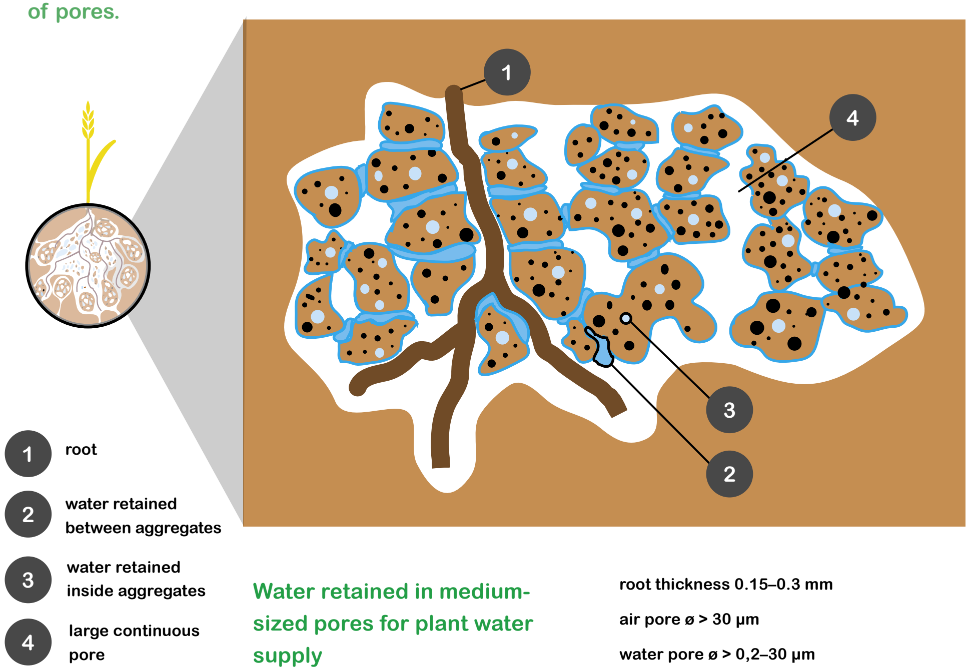
Chemical state

plant nutrients
acidity
harmful substances

Physical state

soil pores:
aeration, water management, mechanical impedance

> Soil structure and functionality of pores.



Water retained in medium-sized pores for plant water supply

root thickness 0.15–0.3 mm

air pore ø > 30 µm

water pore ø > 0,2–30 µm

micropores useless for plants ø < 0.2 µm

In functional soil, the structure made up of soil particles and pores is favourable for plant growth and soil biota: soil retains water and removes excess water, which allows it to remain airy and breath.

Soil needs continuous pores of different size in order to function, remain airy and retain water for use by plants. Small pores have high suction and roots cannot obtain water from them. In such a case, soil is at the wilting point, which equals approximately 30% water content in clay soil. Coarser soils consisting of sand or fine sand release water better, as the proportion of small pores is less than 10%.

Clay, organic matter and micro-organisms create a soil structure that consists of pores of different size. Soil compaction, in turn, reduces porous space by flattening and compressing large oxygen pores in particular. Extensive soil tillage grinds the structure and breaks it up. Organic soils contain more porous space per total volume than do mineral soils. Soil organic matter improves soil's water retention capacity by increasing the number of small and medium-sized pores that retain water against gravity.

Gravity removes rainwater from large continuous pores, which prevents the soil from wetting. In water-saturated condition soil has no oxygen, is dead and swells and breaks up the clayey aggregates and exposes them to erosion. Field traffic on wet soil is very harmful for soil's fertility. In grazing, animal hoofs easily break up the structure of wet soil, which should be taken into consideration in the planning of watering places, for example.

- The pore structure of the soil should be kept favourable by ensuring sufficient organic matter content and avoiding compaction in wet conditions.
- Avoiding high wheel pressures and axle loads especially in wet conditions, making use new technology.
- The most reliable solution to deal with compaction damage is to aim at recovering soil structure with perennial deep-rooting crops.
- Avoiding harvesting in wet conditions in order to prevent compaction.

Soil strength properties influence the ability of soil to withstand harvesting and field machines and anchor the root system. Excessive compaction impairs plant root growth and thus the utilisation of water and nutrients. Poor soil bearing capacity under field and forest machines, in turn, damages the root systems and the growth of crops or trees.

Drainage is necessary in our humid climate and relatively flat land so that water filling up large oxygen pores in soil in wet conditions can be directed away from the root zone. Compaction risk is smaller in drained soil, especially clay soil, which in turn reduces the risk of erosion.[12]

The changing climate and the structural development taking place in agriculture make it difficult to look after the structure of arable land. Rainy winters with no ground frost as well as larger cultivated areas are a difficult combination. Even more sensitive land is cultivated using bigger and heavier machines. Therefore, agricultural land should be allowed to recover at times and sown to grassland, or at least different plant species should be rotated. Mixed crops and cultivars reduce the need for disease and pest management.[13]

> Nutrient ions – from minerals and organic matter.

Roots take nutrients

as ions:

– from soil solution and soil particle surfaces

Total amounts in soil

>> ions in soil solution:

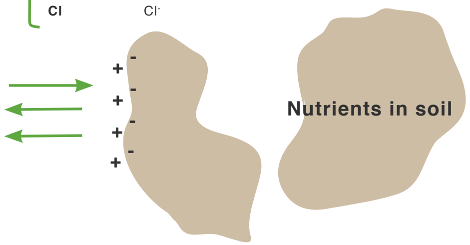
N	NO_3^-, NH_4^+, NH_2^-
P	$H_2PO_4^-$, HPO_4^{2-}
K	K^+
S	SO_4^{2-}
Ca, Mg	Ca^{2+}, Mg^{2+}
B	H_3BO_3, $H_2BO_3^-$
Mo	MoO_4^{2-} , $HMoO_4^-$
Cu	Cu^{2+} , $Cu(OH)^+$, chelates
Fe	Fe^{2+}, $Fe(OH)_2^+$, $Fe(OH)_2^+$, Fe_3^+, chelates
Mn	Mn^{2+}, chelates
Zn	Zn^{2+} , $Zn(OH)^+$, chelates
Cl	Cl^-

Ions are released for roots:

– from soil with a delay

– from manure with a moderate delay

– from mineral fertilisers quickly



Plants need a total of 16 nutrients taken up with water through the root system. Some species also bind nitrogen from the air with root nodules (legumes, alder). The use of manure increases micro-organism action in soil and the release of nutrients from organic matter. Nutrient use efficiency in Finland benefit from liming. However, the rise of the pH above 7 impairs the plant availability of some nutrients, such as phosphorus.

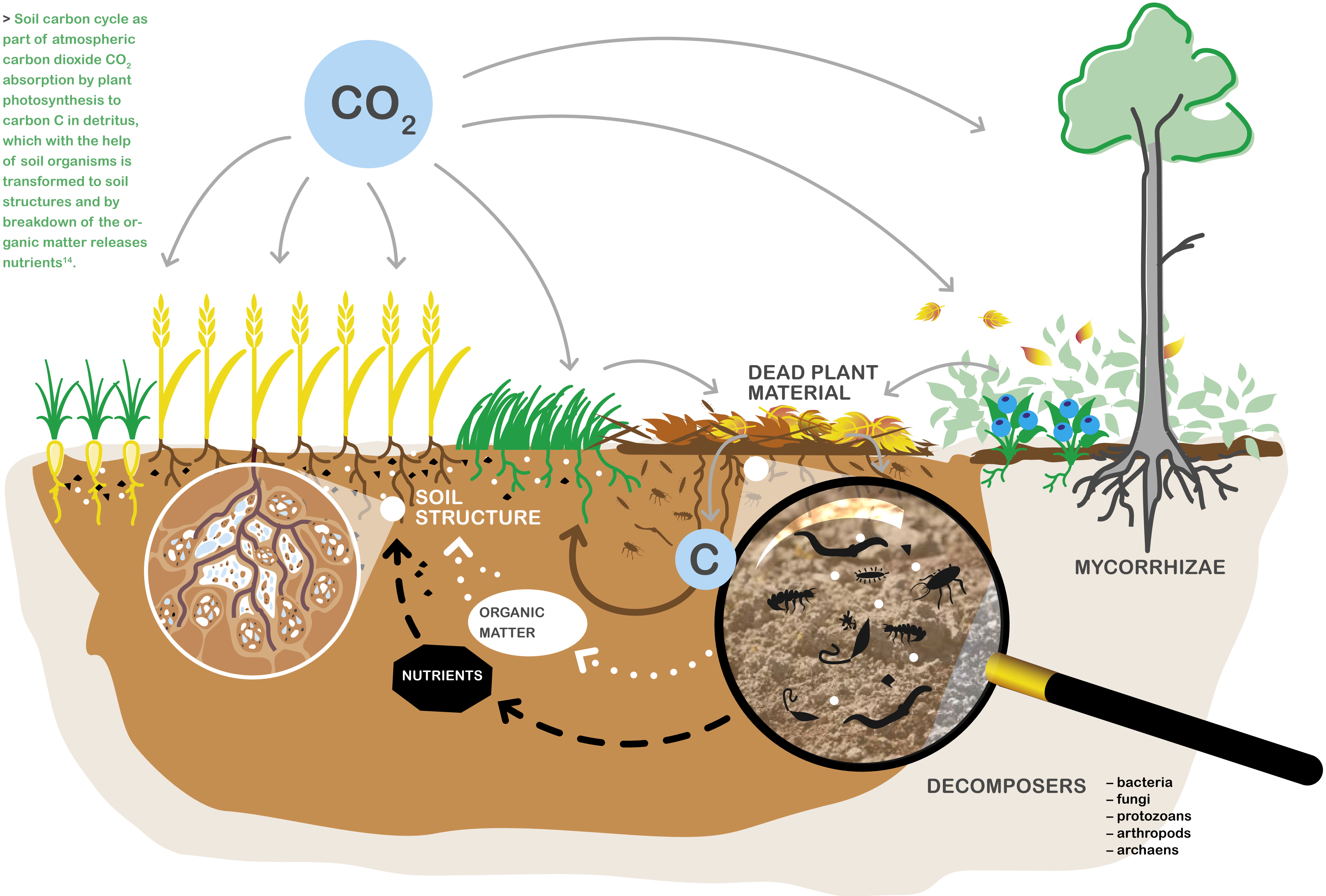
Field crops and forest trees have different nutrient requirements. Spring-sown crops take most of their nutrients before mid-summer, while grasslands and winter-crops sown in autumn utilise soil nutrients throughout the growing season. Forest trees utilise the growing season and the soil's nutrient resources efficiently during decades.

Ecto mycorrhizae living in symbiosis with trees help trees utilise even the smallest concentrations of soil nutrients. Arbuscular mycorrhizae, living within crops, are not as important, partly as a result of plant breeding. Specific plant species, such oilseed rapes or caraway, have no mycorrhizae to help them.

- › Promoting biological soil functions in addition to physical and chemical properties with the help of new data in order to make nutrient use more effective.
- › Securing the functionality of growth factors through the smoothing of field surface, which levels out depressions and balances out rainwater absorption in soil.

> Plant roots and earth worms are essential part of soil vitality.

> Soil carbon cycle as part of atmospheric carbon dioxide CO_2 absorption by plant photosynthesis to carbon C in detritus, which with the help of soil organisms is transformed to soil structures and by breakdown of the organic matter releases nutrients[14].



SOIL QUESTIONS IN AGRICULTURAL POLICY

Only profitable agriculture and security of land tenure allow investments in fertility.

Maintaining and improving the fertility of arable land requires continuous investments. Drainage is a major one-time investment, and resources must also be assigned to its maintenance and improvement, as its efficiency is impaired over the years. In addition, the changing climate with increased precipitation requires improving drainage but also investments to prepare for drought.

Increasing pH with liming is a major investment, but also the maintenance of a suitable pH with regular liming increases cultivation costs.

Maintaining the fertility of soil is only possible when production is profitable. Fair pricing of the products on the markets, fair generation of income in the food chain as well as an encouraging aid scheme allow for profitability.

Soil management calls for long tenure of the land. Almost 40% of fields have been leased and expensive improvements will not be performed under short rental agreements, or the rent is so high that there are no financial resources to carry out improvements.

The EU's common agricultural policy (CAP) and its various aid forms play an important role in directing production in Finland. The basic requirement in most farmer aid granting conditions are terms consisting of good agricultural and environmental conditions related to farming as well as statutory management requirements. Important soil requirements include looking after the condition of soil, cultivation in accordance with good agricultural practices, ban on arable stubble burning, crop cover of set-aside land as well as requirements concerning the use of manure and fertilisers.

The agri-environment climate scheme included in the Rural Development Programme for Mainland Finland plays an important role in promoting environmental actions in agriculture. Other Member States have not implemented them in the same scope as Finland. Some of the measures most important in view of soil have been the specification of fertilisation based on a soil fertility analysis, recycling nutrients and organic matter, different types of grassland, catch and renovating crops as well as plant cover in winter. In the period starting in 2023, a new instrument in the future CAP will be the eco-schemes, whose measures must be related to climate and the environment, for example. Among others, the measures can be used to prevent the impairment of soil condition and improve soil fertility. The eco-schemes help achieve the goals of the European Green Deal.

- Developing aid schemes by setting out from soil conservation and reducing risks based on local conditions instead of strict decrees and date restrictions.
- Taking into account annual weather fluctuations as well as soil properties and their changes when determining granting or compensation conditions for different environmental measures as well as in their control.
- Increasing the flexibility of the measures of the aid scheme supporting environmentally and climate friendly agriculture. It should be possible to change the measures with changes in production.
- Announcing the area of plant cover in winter according to autumn weather conditions before winter, and not in a binding manner in spring.

The primary purpose of agriculture is to produce high-quality food as sustainably and resiliently as possible, so agricultural subsidies must be more consistently directed to food production. Active cultivation includes crop rotation, which improves the condition of soil. It can also be done using nature management fields and other non-feed grassland, such as carbon sink grasslands. This also allows us to adapt to climate change.

- Increasing the visibility of soil measures in active agricultural production. The aim is to obtain a sufficient price for products in order to implement climate and environmental measures.
- Regarding all cultivation seeking to reduce the loss of soil organic matter or increase soil carbon content is considered as carbon farming.
- Making sure that farms can decide on the choice of soil tillage methods. Mouldboard ploughing, for example, may be justified for maintaining soil productivity between years of no ploughing.
- Developing field rental agreements in a way that they encourage to long-term field improvements.
- Developing cooperation models between the lessee and lessor to secure soil improvements.

Leased land should also be looked after

From the land owner's view, fields should be kept in good agricultural condition in view of the future. The required measures entail costs to the lessee, so the highest rent should not be aspired to. When arranging competitive tendering for leasing fields, interested lessee candidates should be informed of the mindset according to which they should take good care of the fields and of the measures that this involves.

Rental agreements in Finland are usually quite short. However, the Land Tenancy Act accommodates longer agreements. The term of the rental agreement can well be 10 years or more. A long rental agreement encourages the lessee to maintain the field's agricultural condition as it ensures that the lessee themselves will benefit from the improvements.

Land rental is a source of income, though good care must be taken of fields and not to aspire towards a better short-term return. The condition of the ownership would otherwise be impaired over the long term and future returns would be endangered. The following should be agreed upon in the rental agreement:

- liming
- maintenance of subsurface drains
- maintenance of ditches
- the use of sewage sludge on fields can be prohibited.

The measures should be agreed upon in writing in the rental agreement, because a condition not included in the agreement is null and void according to the Land Tenancy Act. An appendix can also be attached to the agreement in which the matters have been agreed upon. It should then be indicated in the agreement that an appendix exists and even physically staple the appendix to all agreement copies. The appendix should be dated and signed.

Carbon farming is a new element in the agricultural policy. It refers to the use of measures increasing soil carbon content, i.e. humus content, in agriculture. The measures include agroforestry, rise the groundwater level or reducing tillage in order to slow down the decomposition of organic matter, the restoration of peatland areas into wetland or adding carbon soil improvement materials to the field. The concept can also include the cultivation of different types of mixed crops with deep-rooting plant species. The EU Commission has divided the topic into themes, which include carbon farming for peatlands, agro-forestry and regenerative cultivation.[15, 16]

SOIL ISSUES IN FORESTRY

The recommendations of good forestry in silviculture and the certification of forests guide to adapt sustainable practices that sustain growth and diversity17. The volume production of a site can be increased in forestry through tillage, the fertilisation of growing stands as well as the remedial ditching of peatland areas. As the climate changes, winter harvesting conditions will become poorer and cause the risk of soil damage.

Tillage in forest generation improves the germinative capacity of tree seeds and the growing conditions of saplings. Tillage increases soil temperature, promotes the availability of nutrients and increases soil airiness. Tillage also reduces competition in ground vegetation and the damage caused by pine weevil in saplings.[18]

In forests with mineral soil, ground surface is usually covered by a continuous humus layer. The humus layer is a poor substrate for the regeneration of forest trees, so exposing mineral soil through tillage (scalping, harrowing, ploughing or hummocking) is usually necessary in order to ensure a good regeneration result. Peatland regeneration areas must usually also be tilled.

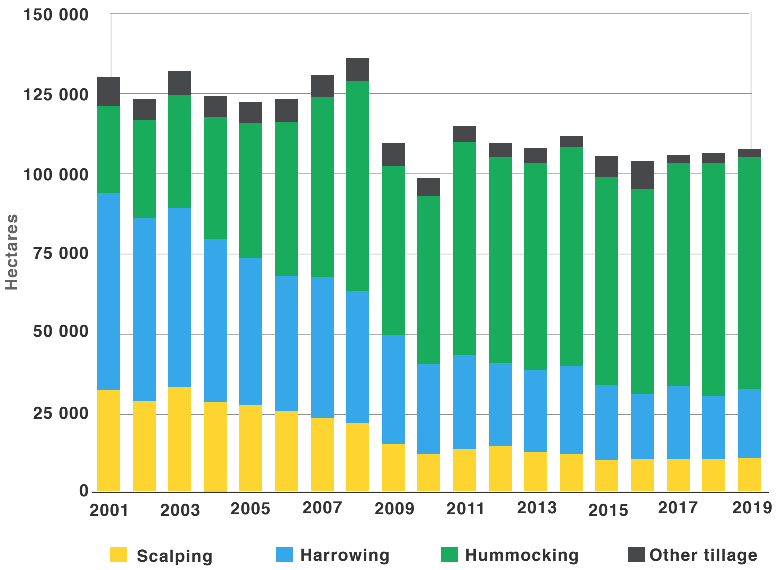
Mechanical tillage was adopted in a broader scale in Finland in the early 1960's. Tillage methods have changed and have been developed in order to improve efficiency and the forest regeneration result as well as to reduce environmental impacts. Currently approximately 70% of the tillage area is hummocked. Annually a total of approximately 100,000 ha is tilled.

Tillage intensifies the leaching of nutrients after regeneration felling. The more ground surface is tilled, the more intense leaching will be. Harmful environmental impacts can be reduced by the correct implementation and timing of tillage as well as leaving untilled protective zones around watercourses. It is difficult to verify the long-term impacts of tillage on vegetation, though tillage is known to harm dwarf shrub vegetation, for example. Tillage can damage rotten trees lying on ground and the species living in them.

So far research results have not provided any clear picture of the impacts of mineral soil tillage on carbon dioxide emissions. The impact may be slight and is affected by soil humidity conditions as well as the amount of fresh, easily decomposable plant material. On mineral soils, mechanical tillage may increase the carbon stock of the whole forest ecosystem in the long term.

- Using a tillage method that is suitable for the site, guarantees forest regeneration but breaks up the ground surface as little as possible.
- Carrying out cultivation briskly after tillage.
- Leaving an untilled protective zone that binds the solid matter and nutrient load and prevents it from entering watercourses.
- Avoiding damage to robust dead wood in tillage.
- Reducing soil damage in harvesting by timing measures and planning tramlines.

> Soil tillage 2000-2019 (Source: SVT: Natural Resources Institute Finland (Luke), Forestry and soil improvement work).



Tillage methods breaking ground surface less have been adopted in the tillage for forest land in the 2000s.[19]

Remedial ditching is used to regulate groundwater level in peatland areas and ensure oxygen-rich conditions for tree roots. 4.7 million hectares of peatland forests have been drained and 0.8 million hectares undrained. Peatland forests make up approximately 23% of the total growing stock in Finland and 20% of forest growth and felling. The majority of peatland forests are in the growing phase, though the proportion of regeneration-ready forests is increasing considerably. In old drainage areas, it is necessary to remedy ditches in order to control water management and to safeguard the growth conditions of trees. Continuous cover forest management has been proposed as one option for remedial ditching, as in it evaporation from trees keeps the water sufficiently low.

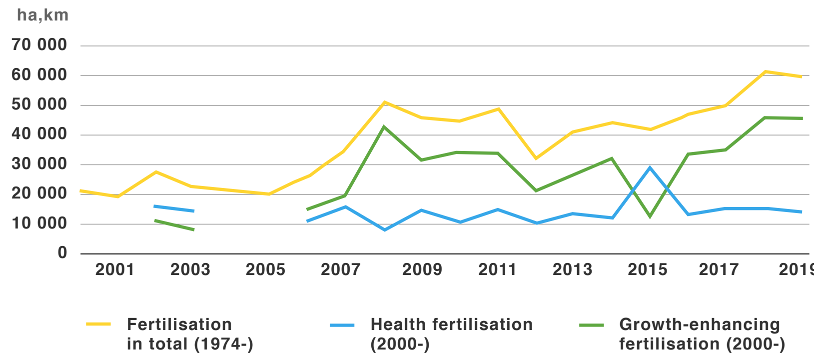
Remedial ditching increases greenhouse gas emissions resulting from soil decomposition in peatland areas. To cut down emissions, the following measures are adopted:

- Increasing continuous cover forest management and ash fertilisation in drained peatland forests.
- Letting drained peatland areas with a small yield to restore.

The aim of forest fertilisation is to improve the growth and vitality of trees by adding nutrients that are scarce in the ground in view of the needs of trees. Fertilisation is the quickest way to increase tree growth and forest carbon dioxide sequestration. Fertilisation on mineral soils increases the volume of trees and also the amount of organic matter in soil. Therefore, it should be noted when examining forest carbon balance that in addition to trees, more and more carbon is also sequestered into soil.

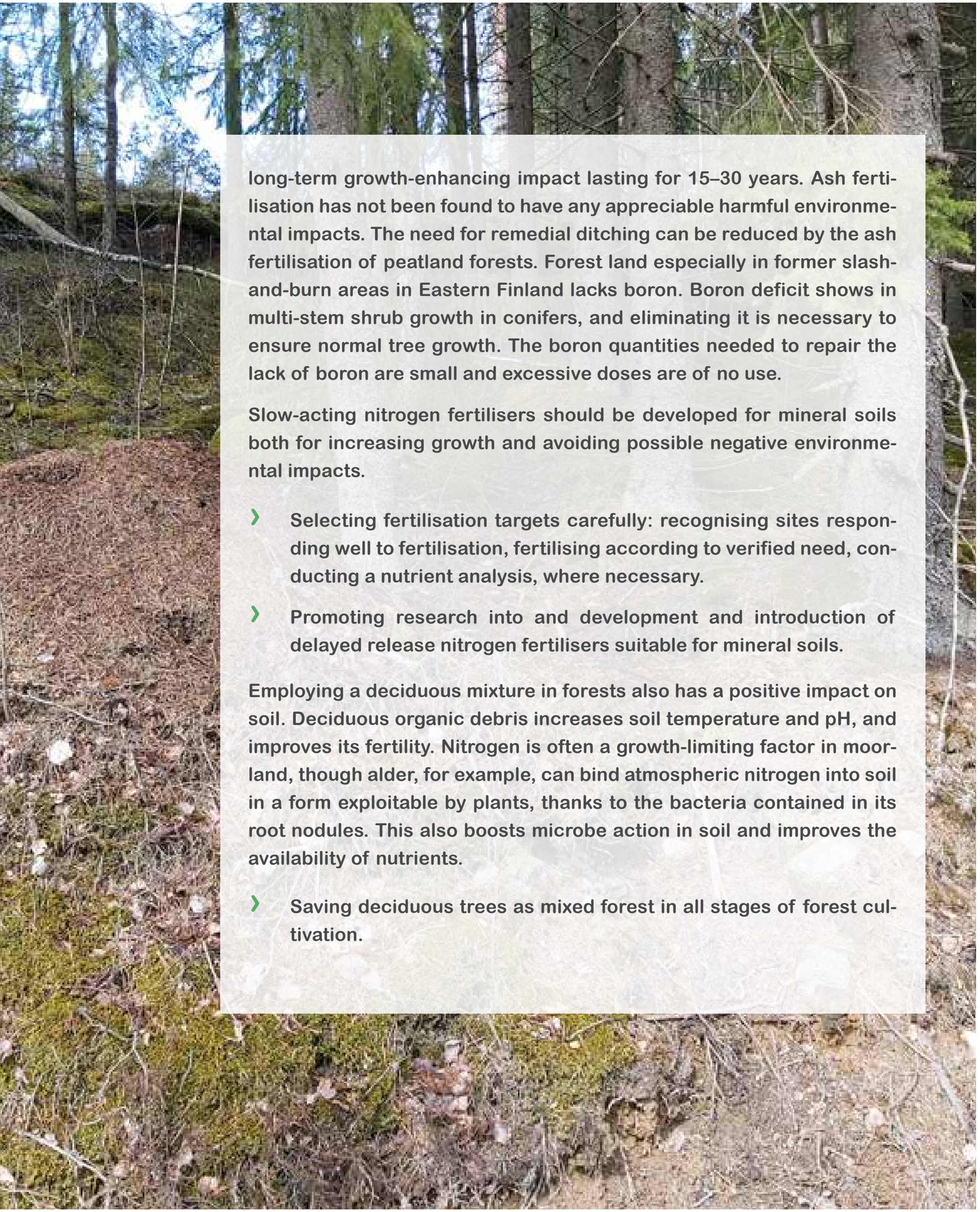
The total amount of health and growth-enhancing fertilisation has been increasing in the last few years. A total of 60,000 hectares were fertilised in 2019.

> Fertilization 2000-2019 (Source: SVT: Natural Resources Institute Finland (Luke), Forestry and soil improvement work).



The lack of nitrogen is the most common growth-impairing factor in mineral soils. Additional tree growth resulting from forest fertilisation is approximately 12–20 m³/hectare during the fertilisation impact period, i.e. approximately 6–8 m³ in one year.

The nutrients management of drained peatland areas differs from mineral soils and the former are more common to have nutrient imbalance that limits tree growth. Ash fertilisation, which repairs the lack of phosphorus, potassium and trace nutrients and limes the soil, can be utilised in peatland areas. Ash fertilisation of peatland areas has a



long-term growth-enhancing impact lasting for 15–30 years. Ash fertilisation has not been found to have any appreciable harmful environmental impacts. The need for remedial ditching can be reduced by the ash fertilisation of peatland forests. Forest land especially in former slash-and-burn areas in Eastern Finland lacks boron. Boron deficit shows in multi-stem shrub growth in conifers, and eliminating it is necessary to ensure normal tree growth. The boron quantities needed to repair the lack of boron are small and excessive doses are of no use.

Slow-acting nitrogen fertilisers should be developed for mineral soils both for increasing growth and avoiding possible negative environmental impacts.

- Selecting fertilisation targets carefully: recognising sites responding well to fertilisation, fertilising according to verified need, conducting a nutrient analysis, where necessary.
- Promoting research into and development and introduction of delayed release nitrogen fertilisers suitable for mineral soils.

Employing a deciduous mixture in forests also has a positive impact on soil. Deciduous organic debris increases soil temperature and pH, and improves its fertility. Nitrogen is often a growth-limiting factor in moorland, though alder, for example, can bind atmospheric nitrogen into soil in a form exploitable by plants, thanks to the bacteria contained in its root nodules. This also boosts microbe action in soil and improves the availability of nutrients.

- Saving deciduous trees as mixed forest in all stages of forest cultivation.

RELYING ON SOIL PURITY

Finnish soil is among the purest in Europe. However, there are also different types of harmful substances in soil. Among others, they can impact soil organisms and fauna, migrate to ground and surface water, evaporate or end up in plants. Soil purity is an important element in food and feed safety.[20, 21]

Finnish soil is among the purest in Europe in terms of harmful metals. The amount of heavy metals is affected by natural soil and bedrock properties as well as emissions caused by human action. Heavy metal loads decreased in the EU countries considerably in the 1990’s, after which the falling trend has balanced out [22,23]. A similar trend has been observed in Finland. Some heavy metals, such as copper and zinc, are important trace nutrients in small concentrations. However, some of them, such as cadmium, led and mercury, are poisonous for biota even in small concentrations. The mobility and binding of heavy metals in soil are impacted by various soil properties, and there are also differences between metals.

Harmful metals end up in fields from atmospheric deposition as well as from inorganic fertilisers and other fertiliser products, manure and liming materials[24]. Heavy metals enter wastewater and wastewater-based fertiliser products from the industry, atmospheric deposition, rainwater as well as human food and different types of preparations, for example[25]. Today many actors in the grain markets do not buy grain yield that has been produced using fertiliser products made from sewage sludge.

According to the Fertiliser Product Act (539/2006), a fertiliser product may not contain harmful substances, products or organisms in such quantities that applying it according to the instructions of use could cause danger to the health or safety of people or animals, plant health or the environment. The Fertiliser Product Decree (Ministry of Agriculture and Forestry 24/11, with its amendments) contains provisions e.g. for the maximum permitted concentrations of cadmium and other harmful metals in the products as well as the maximum load of cadmium in agricultural and forestry use. The decree also provides for the use of wastewater sludge in agriculture.

Finland has an exemption to impose stricter national limits on the cadmium content of fertilisers than the provisions of Directive 76/116/EEC.[26] The EU's new fertilising product regulation ((EU)2019/1009), which will enter into force in summer 2022, will allow Finland to continue limiting the cadmium content of phosphorus fertilisers below the EU's general threshold. This, in turn, will secure pure food production in Finland. The new regulation will apply to inorganic fertilisers and liming materials as well as organic fertilisers and soil improvers, for example.[27]

Organic harmful substances are a very broad group of different compounds, such as fire retardants, coating agents, plasticisers and drugs. Substances vary considerably in terms of their mobility and permanence in soil, which is also affected by soil properties and the prevailing conditions. Some of the substances are very permanent and are found in the environment long after their use has ceased.[28]

Organic harmful substances end up in fields with different types of fertilisers and manure as well as from air deposition, for example. With manure, e.g., drugs and washing chemicals used in animal shelters end up in fields. However, compared with the number animals, the use of pharmaceuticals in Finland is among the lowest in Europe[29]. Harmful substances end up in wastewater treatment plants and further on to sewage sludge and fertiliser products with industrial and domestic wastewater and storm water, for example.

Statutory limit values have not been determined for pharmaceutical residues or other organic harmful substances in fertiliser products. However, actors in the field have developed a voluntary quality system for recycled fertiliser products, in which the concentrations of many harmful organic substances are monitored in addition to statutory quality factors.[30]

Microplastic litter enters agricultural land with cover materials, silage bales and anti-insect nettings as well as farming machine coating materials and tires, fertilisers, pesticides, irrigation water and air, for example[31]. Information is hardly available on microplastic litter found in agricultural land and its soil impacts are poorly known. Information on microplastic litter in agricultural land in Finland is for the first time collected in the ongoing project. Pesticides are used to combat weeds, insect pests and plant diseases, and their use may also entail risks to people's health and the environment. The use of pesticides is governed by legislation on plant protection products.[32]

Some of the products may be harmful to soil organisms if used in successive years or may remain in the soil undecomposed until the next growing season, at which point they may accumulate in soil. A limitation concerning repeated use is imposed on the products, where necessary, in order to minimise their defects. The breakdown of plant pesticides is affected by a number of environmental factors, such as temperature, soil properties, binding of the pesticide as well as the activeness of soil organisms. Their breakdown products may also be harmful to the environment. Plant pesticides can migrate further to surface and ground water from plants and soil.[33]

The situation is much better in Finland than in many other countries: the amount of plant pesticides sold for agricultural use in Finland per hectare in 2018 was the third smallest in Europe[34]. The sales of plant pesticides used in forestry has been increasing since the early 2000s. The product sold most was urea, which is used to combat Annosum root rot. Its share of the total sales of active substances was almost 100%. Urea is used for the statutionary prevention of Annosum root rot (Forest Damages Prevention Act 1087/2013).

Unlike the majority of plant pesticides, urea has not been developed to destroy the spores prevented. Urea's mechanism of action is based on a rise in the stump's pH value, which prevents the spreading of spore contamination from Annosum root rot. Annosum root rot is also prevented using biological pesticides, whose use is based on competition between species. Annosum root rot cannot spread in a stump treated with Phlebiopsis gigantea.

- Ensuring the safety of fertilisers, liming materials and soil improvers through fertilising product legislation. Retaining the provision of strict liability in legislation.
- Not mixing sewage sludge with other raw materials when producing recycled fertiliser products. This increases possibilities to use recycled nutrients.
- Further developing the quality system for recycled fertiliser products by setting limit values for their organic harmful substances.
- Encouraging wastewater treatment plants to adopt technology that ensures the purity of water and solid matter ending up in fertilisation.
- Developing specification sheets for organic fertiliser products to allow farmers obtain exact information on the composition of the products and on the usability of its nutrients.
- Continuing and further promoting integrated plat protection and the moderate use of plant pesticides. Healthy plants bind carbon the best.
- Developing new biological methods for preventing Annosum root rot and improving the usability of Phlebiopsis gigantea.
- Looking after the well-being of animals in a comprehensive manner so that the need for veterinary medicinal products can be kept small.
- Increasing consumers' awareness of how everyone can reduce the migration of harmful substances through wastewater.

COMPLEMENTING THE LACK OF INFORMATION WITH NEW KNOWLEDGE

Soil properties regulate many functions dependent on time and place. It is necessary to measure the cycles of elements and soil liquid and gas flows in-situ conditions to ensure that pollution, or the environmental impacts of cultivation and soil treatment can be assessed. Finland has its own special characteristics, and overseas research cannot replace research carried out in the climate and soil conditions prevailing in Finland.

- Ensuring financing for basic and applied Finnish soil research.
- Increasing knowledge about soil and the profitability of cultivation activities so that soil can be kept clean, healthy and productive in an efficient and cost-effective manner.
- Investigating the condition of soil in agricultural land and its role in yield-level trends, outlining limiting factors and preparing an action plan for addressing them.
- Increasing cooperation with the research community, farmers and forest owners in land surveys and sampling in order to guarantee the relevance and quality of the research.

Permanent properties, such as soil texture, largely determine soil's fertility, though the functionality of pores and the biological activeness of soil are ultimately decisive. The pore structure is often broken in sampling, which limits investigating the various functional properties. Soil texture and the amount of carbon can be measured from a broken sample, and nutrient concentrations extracted. A volumetric sample, i.e. an non-destructive sample, which can be a monolith or cylindrical soil sample, is needed in order determine soil pore structures and measure nutrient fluxes or root system density. Measuring soil gas exchange requires gas samples.

Different states and even universities in Europe have their own extraction solutions in soil testing for determining nutrient availabilityy for plants. As basic soil properties, such as acidity and the characteristics of clays c, affect the results of extraction, interpretation of the nutrient status is based on empirical, practical, experimental research. The fertility analysis in Finland is based on an extraction method that has been in use for 70 years and on practical cultivation tests, which are indispensable for interpreting the fertility analysis in Finnish conditions.

- Clarifying the interpretation of the fertility analysis and classification criteria in order to improve targeted fertilisation practises based on plants' needs.
- Ensuring a successful fertility interpretation through careful site-specific soil sampling. Taking sufficient soil samples according to soil type variation in the field, including subsoil.
- Complementing the fertility analysis with a measurement-based soil type and organic matter content analysis (loss on ignition) in addition to traditional organoleptic assessment.
- Taking soil pore structure and the properties of subsoil into consideration in the assessment of the nutrient load risk of agricultural land, as there are available sorption capacity where phosphorus, for example, is can be retained in Finnish subsoil[35].
- Securing soil data ownership: Farm-specific soil sample data is the property of the farmer, which can be used for research purposes, but for other purposes only with their consent.

Non-destructive soil samples provide information on the functionality of water and gas flows in soil and on nutrient by-pass flows. Field measurements supplement laboratory findings by undisturbed soil cores, as they allow identifying the various layers of the soil profile. Water infiltration rate, for example, which superbly describes soil's performance, must be examined in nature. Observing water dwell time in puddles is a good method for examining the functionality of the soil pore structure.

There is a lot of invisible in soil which cannot be observed. Meters and laboratory analyses must be relied on in measuring gas flows. There is not enough information on the greenhouse gas emissions caused by land treatment in different types of cultivation activities and forest management. More information is needed on the movement of greenhouse gases into soil and from soil to the atmosphere in order to optimise tillage and the regulation of the groundwater level.

Above-ground carbon sequestration can be assessed on the basis of crop yield, knowing that the amount of carbon in dry matter in biomass is 45%. Food and tree producers calculate growth and above-ground sequestration, but what remains under the ground surface? How much gases leak from soil and heat up the climate? Soil is said to be the biggest information deficit in the climate policy.

- Seeking to make the invisible visible, i.e. indicating it in measured numbers that verify the impacts of soil treatment measures on greenhouse gas emissions and sequestration.
- Preparing greenhouse gas sequestration and emission coefficients specific to soil type and cultivation method for use by farms so that farms can outline the carbon cycle and promote measures for carbon-neutrality or preferably make the carbon balance negative.

- Promoting official greenhouse gas emission reporting so that it is based on the natural scientific balance of carbon dioxide sequestration and greenhouse gas emissions by taking account of cultivation measures and soil treatment for different soil types.
- Holding on to ensuring that legislation does not prevent the commercialisation of carbon sequestration in Finnish soil, which will be promoted as the amount of research data increases. Local people must obtain direct benefit from the carbon dioxide market, and the commercial aspect must be seen as an opportunity to improve soil fertility.

In addition to carbon sequestration, practical verification methods suitable for the local conditions are needed in order to secure the biological activeness and biodiversity of soil. The role of fungi in carbon storage is a major opportunity, about which research is expected to provide information for use in conditions prevailing in Finland.

> Soil produces biomass and other ecosystem services, such as carbon sequestration and biodiversity. The carbon markets are evolving, so there is keen demand for carbon sequestration verification methods. Similarly, there is a need for verifying soil measures that promote biodiversity.

In international research, soil classification is based on genetic horizons in the profiles. The whole made up of soil layers having developed in different conditions evolved during millions of years, as in the tropics. The soil formation having occurred in Finland after the Ice Age is a relatively young phenomenon and soil properties hardly differ from the original material. Therefore, the system based on mineral material's soil texture and the content of organic matter has been established in Finland as well as in the other Nordic countries, even though it impairs the international comparison of the external effects of soil, such as greenhouse gas emissions.

Regenerative cultivation is considered to improve soil fertility and economy more than sustainable cultivation. Whether cultivation is regenerative or sustainable, the most important thing is that soil fertility, climate resilience and the state of the environment are improved actively, taking into consideration economy and social dimensions.

- We promote economic research that supports farm-specific planning in soil management and land use. The whole includes special questions related to different soil types without forgetting the drought resistance and productivity of organic soils in a changing climate.

LAND IN OUR CONTROL

Land ownership plays an important role in soil protection. Uncertainty about the land tenure is a global problem that hampers the sustainable use and management of soil over decades. When ownership is clear and stable, it is possible to hand off land holdings to future generations in good condition. This complies with the goals of sustainable development.

Private land ownership is the cornerstone of the Finnish welfare society as well as all economic activities in rural areas. The use of land has been limited through legislation more strictly than other asset categories. If private land areas must be expropriated or the owner's rights deprived in some other way, legislation must guarantee the right market price for the landowners for their loss.

- Improving the constitutional right of protection of property.
- Ensuring that everybody has a genuine right and opportunity to deal with matters concerning their property so that long-term investments in soil improvements can be implemented.
- Seeking to transfer land holdings for non-profit purposes through voluntary agreements based on market prices and ensuring that the transfer is always based on high-quality negotiations with the landowner. No plans should be conducted for private land without informing the landowner of it.

Landowners must enjoy a strong position in land use planning to secure preconditions for rural industries. As land use changes, special attention must be paid to the security of supply and environmental factors by directing construction away from fields and, if this cannot be avoided, away from the fields with the highest crop yield.

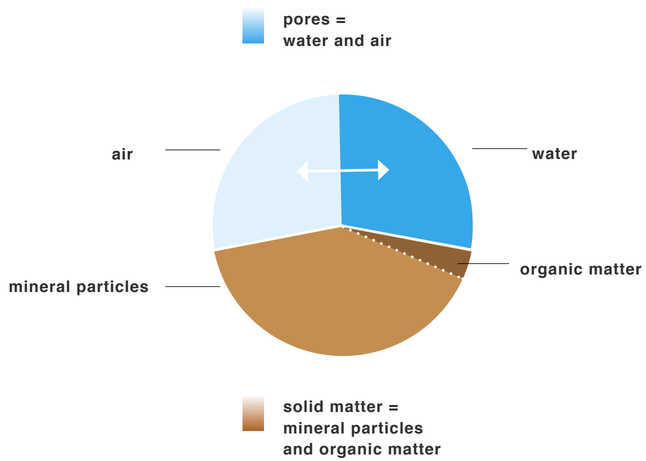
The fragmentation of fields as well as re-routing harms should be avoided and solutions sought that will not increase the pressure to clear more field. Incentives must be available for farmland arrangements, where necessary.

- Using agreements to promote the use of farms that extend the possession of a productive field, which eliminates the need for clearing fields.
- Securing a stable, predictable operating environment for agriculture and forestry in the use of land resources.

Soil has many duties. It acts as a cultural heritage and enables nature regulation and maintenance services as well as services related to the production of food, energy and raw materials. Soil ecosystem services offer carbon sequestration, water purification and storage, nutrient cycling, pest management and recreation. Therefore, soil is decisively important in combatting climate change, protecting people's health and securing biological diversity and food security. It is necessary to increase actions that protect soil fertility, reduce erosion and increase the amount of organic matter in soil. Major progress is also needed in the identification of contaminated areas, determining a good ecological state, recovering soil's impaired productivity as well as improving the monitoring of soil quality.[36, 37]

SOIL CLASSES AND ORGANIC MATTER CONTENT

Soil consists of solid matter (inorganic and organic) and pores. It is in close interaction with air and water that fill the pore space. The soil texture of inorganic matter in soil, the amount of organic matter as well as the soil's aggregation and pore structure determine the environmental sustainability of farming.



In Finland, mineral soils are determined according to their texture, in organic soils according to the amount and quality of organic matter and in alluvial land also according to origin (e.g. mud clay). A frequently used soil type classification criterion in the world is soil genesis. The creation, distribution and stratification of soil type formations in young Finnish soil depend on the phases of the continental glacier. Sorted mineral soils are classified as clay soil if the proportion of clay is 30% (60% in heavy clay). Mull is a topsoil type in cultivated fields, containing 20–40% of organic matter. Mull was typically created when a thin peat layer was mixed with the underlying mineral soil in tillage.

> Soil types according to particle size in arable and forest land [38].

Grade Ø, mm	Classification used in agriculture	GEO classification
<0,002	clay	clay
0,002–0,006	fine silt hHs	fine silt
0,006–0,02	medium silt KHs	medium silt
0,02–0,06	coarse silt HHt	coarse silt
0,06–0,2	fine sand KHt	fine sand
0,2–2	fine sand HHk	medium sand
0,6–02	coarse sand KHk	coarse sand

> Organic matter categories in arable soils by the soil fertility analysis and the corresponding carbon and carbon dioxide equivalent (CO_2 equiv.) concentrations, % of soil volume[38].

Soil organic matter content , %	Name	Carbon, % [39]	CO_2 equiv., %
less than 3	low in organic matter	<1,7	<6
3–5,9	medium content in organic matter	1,7–3,49	6–12
6–11,9	high in organic matter	3,5–6,99	13–25,9
12–19,9	very high in organic matter content	7–11,63	28–42,9
20–39,9	mull	11,63–23,26	43–84,9
>40	Peat (e.g. Carex peat or Sphagnum peat)	>23,3	>85

Soil biological, chemical and physical properties affect functions like carbon cycling, water storage and nutrients availability for plants. Mineral soil works optimally in food production when contains at least 4–6% of carbon and the clay/carbon relation is below ten[40].

MEASURES FOR INCREASING THE AMOUNT OF ORGANIC MATTER IN ARABLE LAND

MOST IMPORTANT ONES:

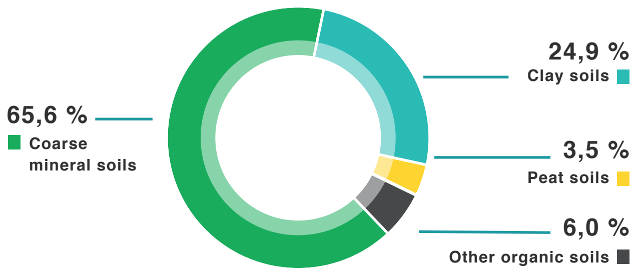
- Use of manure
- Crop rotation in perennial grasslands
- Cultivation of plants with an abundant root system
- Increasing yield

DEPENDING ON COMPOSITION [41]

- Sludge
- Fibres and biomass-derived black carbon

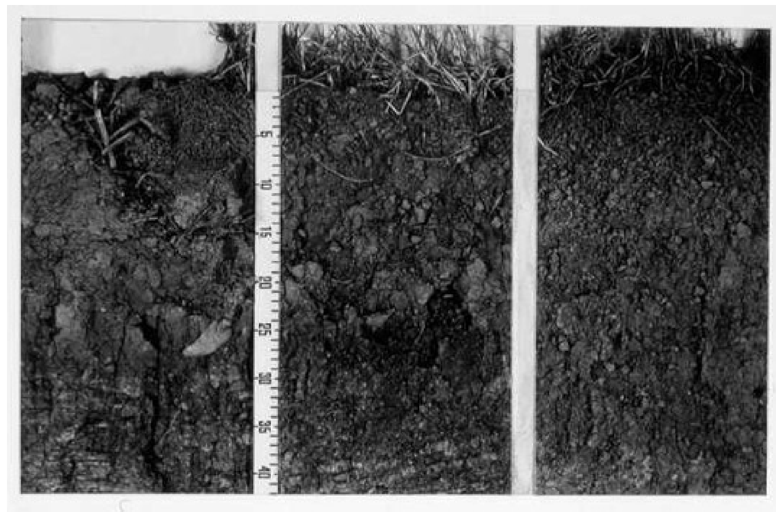
> Top soil humus content % of samples 2016 –2019. (Source: Eurofins Fertility service 5 February 2021).

> Soil type relations in top soil % of samples 2016 –2019. (Source: Eurofins Fertility service 5 February 2021).



SOIL STRUCTURE AND HORIZONS

Soil profile shows the stratification of soil and variation in soil properties over time. As a result of cultivation the plough layer is darkened by decomposing plant debris under the temporary moisture front (left). The most typical soil in Finland is podzol (right) developed over the millennia. There is a light layer from which nutrients have been washed away under the surface layer darkened by decomposed organic debris, and a red brown illuvial horizon deeper, coloured by iron compounds.



A series of photos taken over a few decades ago shows how continuous grassland leads to aggregation in compacted clay soil: in the left, 10 years of crop cultivation and ploughing, in the middle, 4 years as grassland after the annual cultivation and in the right 10 years as grassland[42].

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BASED ON:

- Effectiveness and balance of growth factors
- Safe inputs
- High-quality measurement
- Protection of land property

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