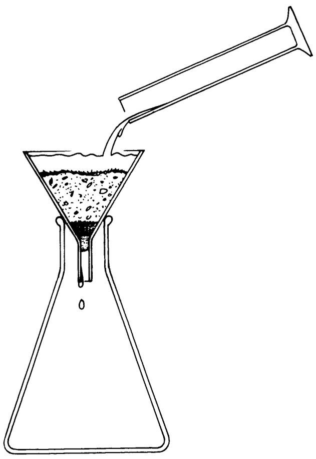
HANDBOOK
BIOLOGY

J. Mayer

Examination of soil

Chemistry



Environmental Atlas Soil

Biology

30836.02

PHYWE – Series of Publications J. Mayer

Handbook
Examination of soil

PHYWE-Series of publications
Order No.: 30836.02

1st Edition
All rights reserved, including those for translations, reprinting in part and photomechanical reproduction
Desktop-Publishing: Hildegard Richard DTP, D-37115 Duderstadt

© PHYWE SYSTEME GMBH, D-37070 Göttingen

Contents

1. What is soil?

When various specialists who deal with soil, such as biologists, geologists, geographers or soil scientists, give you a definition of the term "soil", you will find you have many differing versions. Each of them will mirror the point of view of their individual branch of science, and could be as follows:

— "*Soil* is a fundamental component of the terrestial ecosystem, it serves as a locality for higher plants and is the habitat of numerous animate beings".
— "*Soil* is a substrate that conveys air, water and nutrients to organisms".
— "*Soil* is the living layer of the earth's land surface which is positioned between inanimate material (the so-called lithosphere) and the air (the atmosphere)".
— "*Soil* is the transformation product of the lithosphere (rock) under the influence of the atmosphere (air), hydrosphere (water) and biosphere (living beings)".

Schroeder gave a definition which includes many of the aspects of soil:

— *"Soil is the transformation product of mineral and organic substances. It is interspersed with water, air and living things, has been formed by the influence of environmental factors on the earth's surface, develops further in the course of time and has its own morphological organization, as well as the ability to serve as location for higher plants and to be the habitat of animals and human beings".*

Fig. 1.1 lists possible themes and their contents, which represent different aspects of the theme soil and each of which belongs in a comprehensive definition.

Fig. 1.1: Structuring of the range of the theme "Soil"

Theme	Discipline	Content
Soil is composed of various components	Soil morphology	Humus, soil texture, soil structures
Soil is undergoing development	Soil genesis	Weathering, soil formation, soil development
Soil is structured; there are various soils	Soil morphology, soil systematic	Soil horizons, soil profiles, soil types
Soil has various properties	Soil physics, soil chemistry	Structure, compactness, acidity, buffer capacity
Soil is a site factor for plants	Geobotany	Nutrients, water balance, soil reaction
Soil is a habitat for living things	Soil biology	Edaphon, nutrient network
Soil fulfils functions in the ecosystem	Soil ecology	Production functions, control functions, habitat functions
Soil structures landscapes	Soil geography	Groups of soil, soil regions
Soil is of importance to man	Soil utilization, soil protection	Land utilization, soil pollution, soil protection

2. Soil consists of various components

Soil is – in contrast to minerals, plants or animals – not a sharply differentiated natural body. It is a "an environmental medium which is put together", consisting of

1. mineral components (rocks, minerals),
2. organic components (dead plant parts, dead remains of animal, humus),
3. water, and
4. air.

2.1 Mineral components

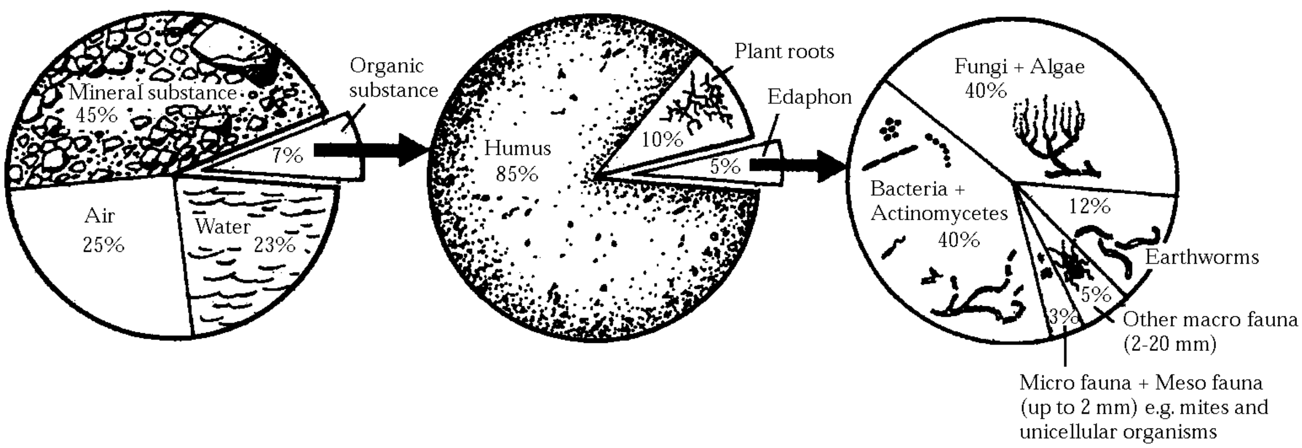
The mineral components of the soil make up the largest part of the solid soil substance (exception: the peat soils of moors). As an almost unchangeable quantity, they influence all soil properties and so also the potential utilization of the soil. The particle size, chemical constitution and also the age of the mineral substance are of particular importance.

The mineral soil components are closely related to the original parent rock, but are not identical to it, as the mineral is chemically changed and in part newly formed.

Soil texture

The minerals are of various particle sizes, according to the original material and the degree of weathering. According to definition, particles of size 2-0.06 mm are called sand, those of 0.06-0.002 mm silt and those smaller than 0.002 mm clay. Natural soil always consists of a mixture of various particle sizes. A relatively balanced mixture of particle sizes is called loam. This mixture of various mineral particles of different sizes, i.e. the relative amounts of sand, silt and clay in a soil, is called the soil granulation or soil texture.

Fig. 2.1.: The composition of soil



Almost all physical and chemical properties of mineral soil are determined by the quantities and distribution of the various components, i.e. by the soil texture. For example, the storage and availability of water and nutrients, swelling and contraction, formation of soil structure and culturing capability. Table 2.2 provides an overview of important soil properties in dependence on the soil texture.
It can be seen from this Table that soils with balanced proportions of the various particle sizes (e.g. loam) have favourable soil properties. These favourable properties have a positive effect on their yield.

2.2 Organic components

The organic soil substances, the largest part of which is humus, together with the mineral soil substances, form the solid body of the soil. Both pass through similar decomposing and structuring processes, and together they form the clay-humus complex, which makes up the actual soil structure (see Fig. 3.2).
The organic substance in mineral soils consists on average of: 85% dead organic substance (= humus), 10% plant roots, 5% edaphon (soil flora and fauna). Coarser plant material, such as root-stocks and larger plant roots (diameter greater than 2 cm) and higher vertebrates which live in the soil, are by convention not included under organic soil substance.

Fig. 2.2: Soil texture and soil properties

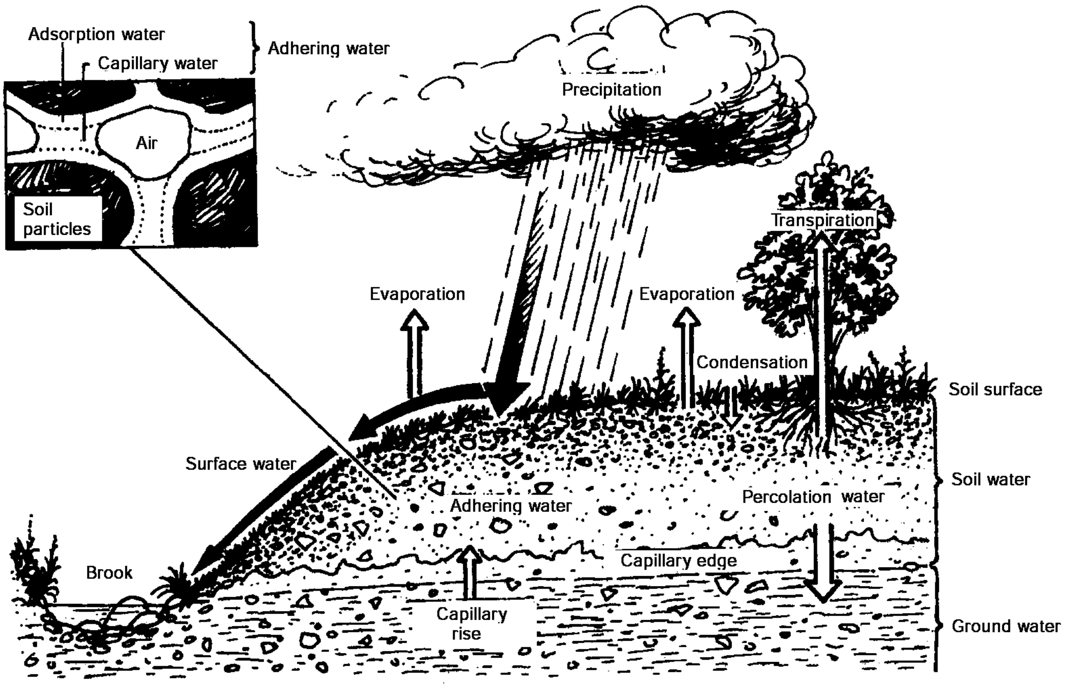
Property	Sandy soil	Clayey soil[1)]
Soil particles	predominately large > 0.1 mm	Predominately small < 0.01 mm
Pore-size	large	small
Air content in vol%	30-40	0-15
Aeration	intensive	bad
CO_2 content of the soil air in vol % at 15 cm soil depth	0.14	0.27
Water capacity	low	high
Water drainage	good	bad
Holding capacity for nutrients	low	high
Warming	good	bad
Rooting	good	bad
Cultivation	easy	difficult

[1)] Loam soil takes up a middle position between sandy and clay soils.

Humus
The accumulated, decayed remains of plants and animals are called *humus* (latin = moist, fertile soil). Humus gives the soil a characteristic dark colour. Different humus profiles, shapes of humus and kinds of humus can be distinguished in bodies of humus, in a similar way as with mineral soil substance.
The following types of humus are distinguished, according to the function which the various humus substances have in the soil. Substances which are easily microbially transformed form *crustable humus*, which is predominately mineralized and so contributes to the additional supply of nutrients. Substances which are hardly subject to microbial transformation form the *stable humus*, which acts as a structural element in the soil by binding water and adsorbing nutrients.

2.3 Soil water and soil air
Alongside the solid soil components, mineral bodies and humus, soil consists of a system of hollow spaces which are filled with water and air. Soil water and soil air have a great influence on practically all processes occurring in the soil. Soil water in particular also has a direct effect on plant growth at the corresponding site.
Soil water is one of the prerequisites for a soil to be able to live and fulfil its diverse functions for plant growth. The storage of water in soil is, however, dependent on the mineral and organic components (humus). Soil water is the name given to that part of the water which can be removed from the soil by drying it at 105°C. The water of crystallization remaining in minerals after such drying is assigned to the solid soil mass. Soil water is replenished by precipitation, ground water and condensation from the atmosphere. When precipitation supplies more water than the soil can hold, the excess flows off as surface water (see Fig. 2.3).
Soil water can only move freely to a limited extent in the pores of the soil. The largest part is bound to the soil matrix (solid soil components).
As the kind of binding influences the behaviour of that particular portion of water, soil water is often classified according to the kind of binding.
Percolation water (*gravitational water*) is that part of water which is not held by the soil, and so seeps to deeper zones.
Adhesive water is that part of the soil water which is held in the pores against the influence of the force of gravity. Adhesive water is held either as adsorbed water on the surfaces of solid soil particles or as capillary water in pores and capillaries.
Ground water and stagnant water is that part of the percolation water which collects above water impermeable layers (see Fig. 2.3).

Fig. 2.3: Schematic of the distribution of soil water



The presence of soil air is a prerequisite for the respiration of plant roots and of organisms which live in the soil. The composition of soil air differs from that of the atmosphere. The respiratory processes in soil result in a shift towards a higher CO_2 content and a lower O_2 content. Gas exchange by diffusion, so-called soil respiration, acts against this difference in the compositions of soil air and the atmosphere. This is of importance in as much as a slowing of plant growth is to be reckoned with at an oxygen content of less than 10%. Good ventilation of soil is therefore necessary.

The following is valid for the relationship between the balance of water and of air:

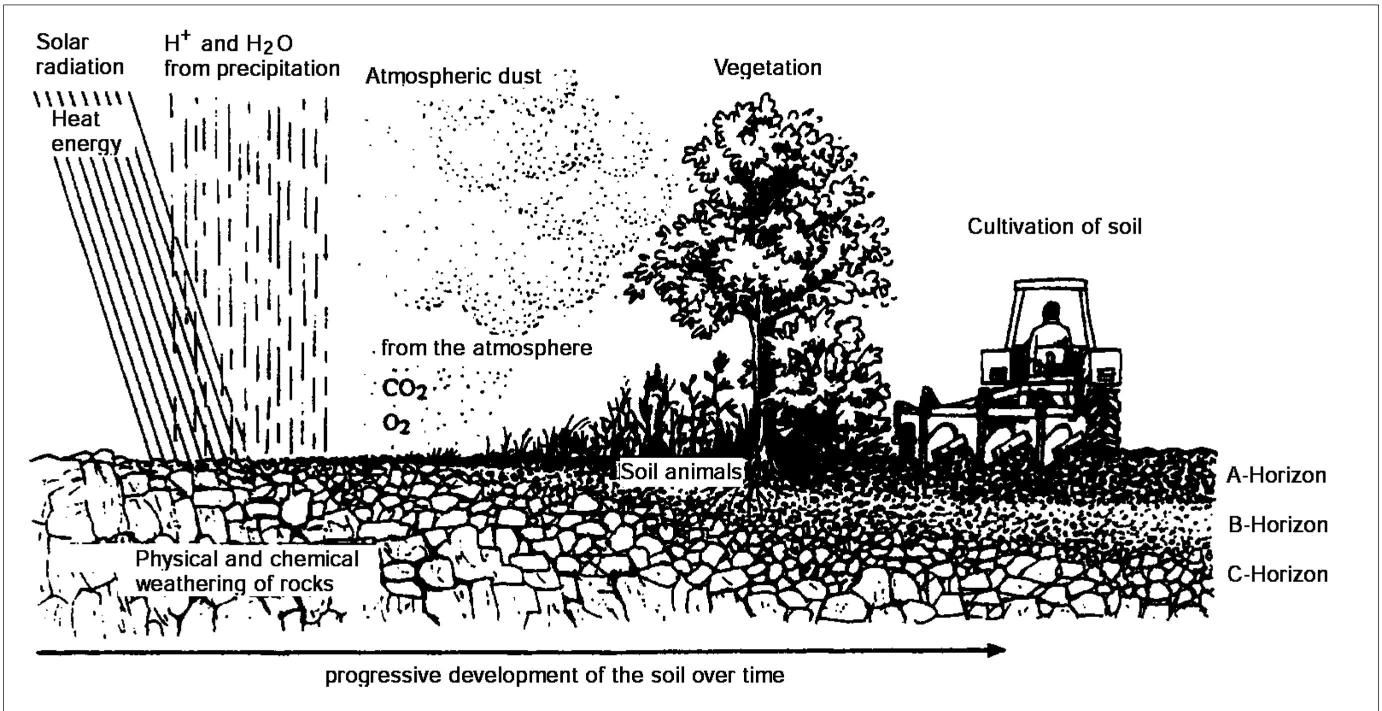
— *Soil water and soil air together fill the soil pores*, i.e. the hollow spaces between the solid soil components (minerals, humus).
— *Soil water and soil air displace each other from these pores*, so that the lower the air content is, the higher the water content is, and vice versa.
— *Soil water* is mainly to be found in the small pores, *soil air*, on the other hand, in the large pores of the soil.
— *The pore system (quantity and size of the pores)* is dependent upon the soil structure (sand, silt, clay), its humus content and the structure of the topsoil.

3. Soil undergoes development

Soils generally have a long history of development, and this results in distinctions between various bodies of soil (see Fig. 3.1).

The original mineral material from which soil is formed is solid or loose rock. The latter can have been deposited by glaciers, water or by wind. The rock is broken up by physical weathering, e.g. large variations in temperature cause crevices to form in the rock, water in these exerts a splitting action on the rock when it freezes. In addition to this, chemical weathering occurs, e.g. carbonic acid in solution in water causes chemical changes in the rock. Finally, biological weathering occurs from the actions of plants, animals and microorganisms, e.g. from mixing of the soil, or from excretion of metabolic products. These initiate further chemical and physical weathering processes. As a result of weathering, ions are released from the rock, and these serve as nutrients for plants. When the plants die, they are decomposed by animals, fungi and bacteria, and humus, a transformation product from organic material, is formed from the decomposition products, microorganisms and remains of dead animals. A part of the humus is decomposed to nutrient salts, which are taken up by plants. Through the weathering of rocks and their population with living things which produce and decompose organic material, soil is created in a cyclical process and is subject to continued development.

Fig. 3.1: The formation of soil and soil horizons



The development of soil is not characterized alone by decomposition processes, however, but also by formative processes (see Abb. 3.2). Important new products are clay minerals and humus substances.

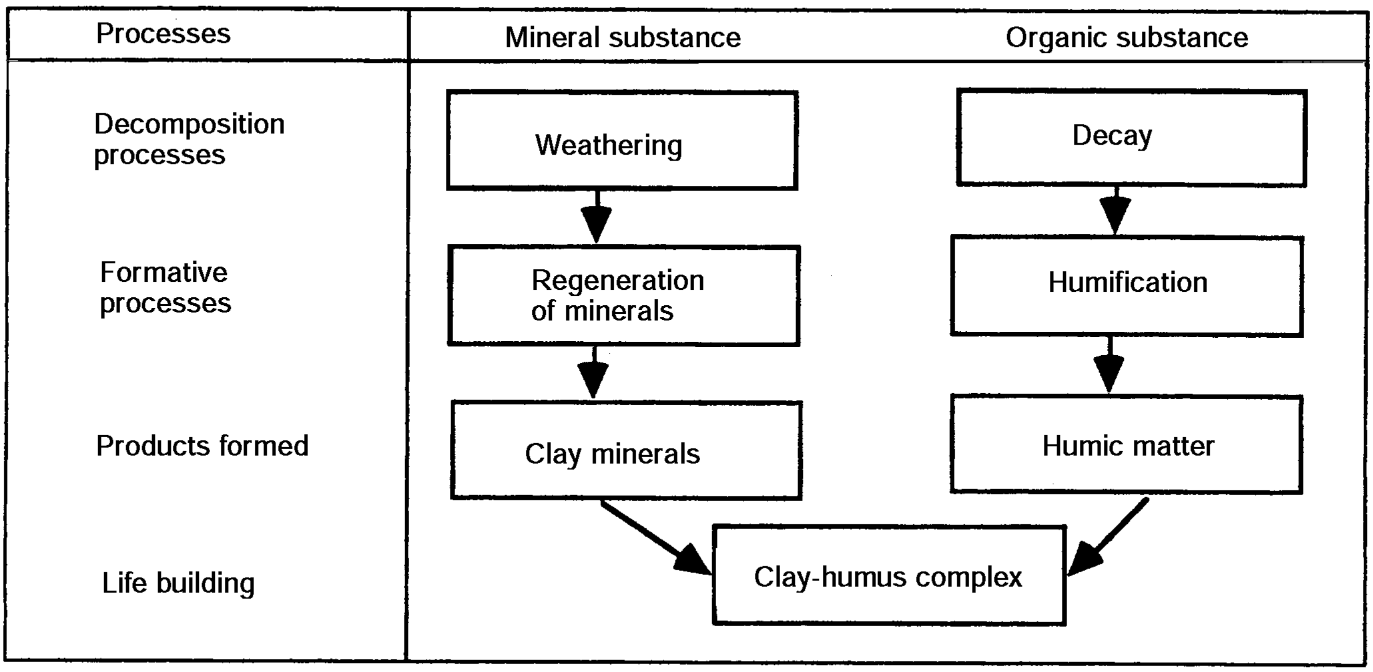
Clay minerals are formed during the weathering of mica and felspar, both major components of granite.The fine laminae of mica, which consist of hydroxyl-containing aluminium silicates, are held tightly together by potassium ions. During weathering, the potassium ions are replaced by water molecules and the layers separate somewhat and are now only loosely bound to each other. Salt cations are also bound alongside water molecules in the intermediate space. These cations constitute the nutrient salt richness of a clay soil. They can be displaced, for example, by H^+ ions and then be taken up by roots. Clay minerals have a diameter of < 0.002 mm. They swell on addition of water. This property is responsible for the plasticity and the water storage capacity of clay.

Humus formation results from the decomposition of primary organic starting material by soil organisms. During this, there is either a degradation to molecular and ionic end products, or a conversion or build up to new secondary humus substances. The degradation process occurs by hydrolysis and oxidation, mechanical break-down and microbial decomposition. The formation of secondary humus substances is called humification. When the conditions are not optimal for decay or humification, e.g. when there is a lack of water, an excess of water or a lack of air, or when the temperature is low, the soil is acidic or the starting material is difficult to convert, decomposition is delayed and potentially convertible organic substances accumulate.

3.1 Factors for soil formation

The development of soil is highly dependent on its *structure, mineral content and texture*. Loose sediment, for example, weathers more easily than solid rock, whereby the corresponding soils are deeper. The *climate* (average course of the weathering) acts directly on soil development via warmth and precipitation and indirectly via the vegetation, which is influenced by the climate. The climatic factor which is the greatest driving source for the development of soil is energy from the sun. The *relief (altitude, relief, exposure)* modifies soil development, through its effect on gravity, climate, rock, water, life in general and man. The local climate differs particularly between northern and southern slopes. The temperatures of air and soil, the intensity of light as well as evaporation are generally lower on northern slopes than on southern slopes. Because of this, the soils are wetted more strongly and to a greater depth, and are often deeper than on southern slopes, but at the same time there is less intense weathering because of the lower temperatures. In addition to precipitated water, ground water and still or flowing water also act on the development of certain soils. With regard to vegetation and soil fauna, it is first of importance to *soil development*, that the particular vegetation supplies a litter of various organic starting materials for soil. Besides this, vegetation draws water and nutrients from the soil, forms a protective covering over the soil surface and excretes organic acids and complex formers, which influence the weathering process. *Man* acts via soil utilization both directly and indirectly on changes in climate, relief, rock, vegetation or water. Agricultural utilization increases the flow of percolation water, increases erosion and greatly changes the upper horizon.

Fig. 3.2: Soil development processes



3.2 Soil development processes

Physical, chemical and biological processes are all involved in *weathering*. Soddiness and temperature essentially control the type and speed of weathering, which leads to profile differentiation. Chemical solution weathering means the neutralization of acids, whereby incomplete buffering of the soil leads to acidification, debasing and liberation of (toxic) aluminium ions. *Loaming and "browning"* lead to new mineral formation from clay minerals and iron oxides, which results in a reshaping of the initial rock to a clayey brown coloured soil. *Decomposition and humification* of organic substances which come into the soil lead to liberation of nutrient ions, only a small part is fixed as stable humus. The downward shift of components of clay fractions from the topsoil to the subsoil is called *clay translocation* (lessivage). It causes a redistribution of nutrient reserves, and can lead to a breakdown in the structure in the topsoil and the clogging of small pores in the subsoil. The downward directed relocation of dissolved organic substances, often together with aluminium and iron, is designated *podzolization*. It leads to a redistribution of nutrients, particularly of Fe, Mn, Cu and P.

The relocation of dissolved iron and manganese caused by rising ground water is called *gleyization*, that caused by stagnant water *pseudo-gleyization*. Dissolution of the metal ions takes place under a lack of oxygen – under reduction – and causes a bleaching of the horizon. Precipitation occurs under abundance of oxygen – under oxidation – and leads to iron spots or concretions, and to enrichment of the nutrients Fe, Mn, Cu, P and Mo in oxidation horizons.

4. Soil has various horizons

Because of soil development, soil is not uniformly structured throughout its depth. Soil development begins as a rule at the surface of a rock and progresses in depth in the course of time. Layers are formed which differ in their properties and which are called soil horizons. At the top of the soil they are litter-like, and become increasingly rock-like with increasing depth. They have been formed during the course of the soil development, and mirror the history of the development of the soil.

4.1 Soil horizons

The bottom layer is the *rock horizon (C-horizon)*; it is made up of more or less unchanged parent rock material. Above this is the *subsoil horizon (B-horizon)*; this is characterized by the increased weathering of the rock. It has a typical red-brown colour from liberated iron oxides. The layer at the top is the mineral *topsoil horizon (A-horizon)*. This is full of life and roots, and distinctly darker coloured than the horizons below because of the humus it contains. Locations close to being natural (e.g. forests) lie on layers dominated by organic material (O-horizons), consisting of more or less decayed organic material (e.g. litter, humus, peat). Further horizons which are not so frequently encountered can be also be differentiated, e.g. E-horizons (horizon in which the main feature is loss of clay, iron or aluminium, leaving a concentration of sand and silt particles).

Such distinct horizons are no longer to be found in soil used for agricultural purposes, as the topsoil and subsoil horizons are mixed by ploughing. A so-called mollic A horizon develops.

4.2 Soil types

The soil horizons can be found in various forms, combinations and succession, and so make up the soil profile of a particular soil. Soils having the same soil profile mirror the same stage of development, and are therefore put together in a genetically determined soil type. There is a systematic for the soil types which is similar to the systematic for biology. In dependence on the original rock, the relief and climate, the living things in and on the soil, as well as the duration of the influence of various soil forming factors, there is a certain soil type at each location (classification according to the FAO/UNESCO Soil Map of the World):

Leptosol: Soils which are limited in depth by continuous hard rock or highly calcareous material. Leptosol is a weakly developed soil and is found on hillside locations.

Chernozem: Soil with a thick Ah-horizon containing mull and with an optimal crumb structure, also on a loess subsoil. Chernozem is formed under a continental climate with long, cold winters and dry, warm summers (the climatic conditions which prevailed in North Germany 10,000 years ago), whereby the decomposition of organic substance is inhibited. Chernozem can be found in the Magdeburg plain and in the Hildesheim and Erfurt areas. Such soil has the highest potential fertility, because of the favourable water balance, neutral reaction, high base-saturation but slowly flowing nitrogen reserves.

Cambisol: Cambisol has a humous A-horizon, which merges into a brown coloured B-horizon, under which is a C-horizon. It is produced from Leptosols by progressive silicate weathering (loaming and browning).

Luvisols: Soils with migration and illuvial accumulation of clay. The clay shift results in a loss of nutrients and a low structural stability.

Podzol: Podzols have a thick, low-nitrogen, acidic humus horizon. The A-horizon (bleached horizon) is depleted in iron, clay, bases and nutrients. The B-horizon can, on enrichment with Fe, harden to a dense, hard ironpan. Podzoles are found in particular in North Germany and in higher regions of the uplands. Their development is favoured by free draining low-silicate as well as low base and nutrient rock, and further by plants supplying raw humus.

Gleysols: Gleysols are characterized by ground water. The permanently wet, pale gray to grayish-green , also bluish-black horizon is on a rust-like horizon, which is on the, from ground water uninfluenced, Ah-horizon.

5. Soil has various properties

Because of the specific components, the composition and the layering, a soil is distinguished by various physical and chemical properties. As a result of these various properties, the soil exhibits a characteristic behaviour towards environmental influences and measures for utilization. The most important physical properties of a soil are the soil compactness, consistency, temperature and colour.

Soil compactness:

The soil compactness (density) gives the relationship between its mass and volume. It has a value of approx. 2.65 for mineral soil substance, and approx. 1.4 for organic substance. The soil consistency describes the degree of cohesion of the soil particles. It is of particular importance for the penetration of roots through the soil and for the cultivation of the soil.

Soil temperature:

The soil temperature, as a measure of the thermal energy which a soil contains, is of importance for practically all chemical and biological processes in the soil.

Soil colour:

The colour of the soil is an important diagnostic feature of a soil. It supplies information on the humus content, Fe compounds and oxygen.

Soil pH:

The acid content, measured as pH, is one of the chemical properties of soils. It is of importance in as much as a soil with a slightly acidic to neutral pH (pH 6-7) has the best physical and biological properties for plants and soil life. The acids which are responsible for the pH of the soil are in part formed in the soil, but also brought into the soil by acid rain and other anthropogenic sources.

Internal sources of acids in soil are:

— Carbonic acid, coming from the respiration of microorganisms, plant roots and soil animals.
— Humic acids, various very complex acids formed during the conversion of organic substance to humus.
— Nitric acid, which is formed in the nitrogen cycle by the decomposition and conversion of organic substance.
— Hydrogen ions, which are given off during the intake of nutrient by plant roots.

Anthropogenic sources are:

— Sulphuric acid, nitric acid and carbonic acid from acid rain, and
— nitric acid, formed from acid-forming fertilizer (ammonia, liquid manure from animal refuse).

Because of the internal soil sources of acid, and the fact that even unburdened rain is slightly acidic (pH), a gradual acidification of the soil must be described as a natural soil development process in the central European climate. This process, which would take thousands of years, will however be greatly accelerated by the anthropogenic supply of acids.

6. The soil in the ecosystem forest

The occurrence and the development of living communities in an ecosystem such as, for example, a forest, depend upon a number of environmental factors, which are designated as biotope in their entirety. The soil belongs to the abiotic environmental factors, together with climate and relief. The soil fulfils numerous important functions in an ecosystem: It is a site for plants, regulates the water balance, converts and stores nutrients, acts as filter and buffer against harmful substances, as well as being a habitat for soil organisms. These functions can be qualitatively described or quantitatively determined by means of the corresponding test procedure.

7. Plant communities and soil

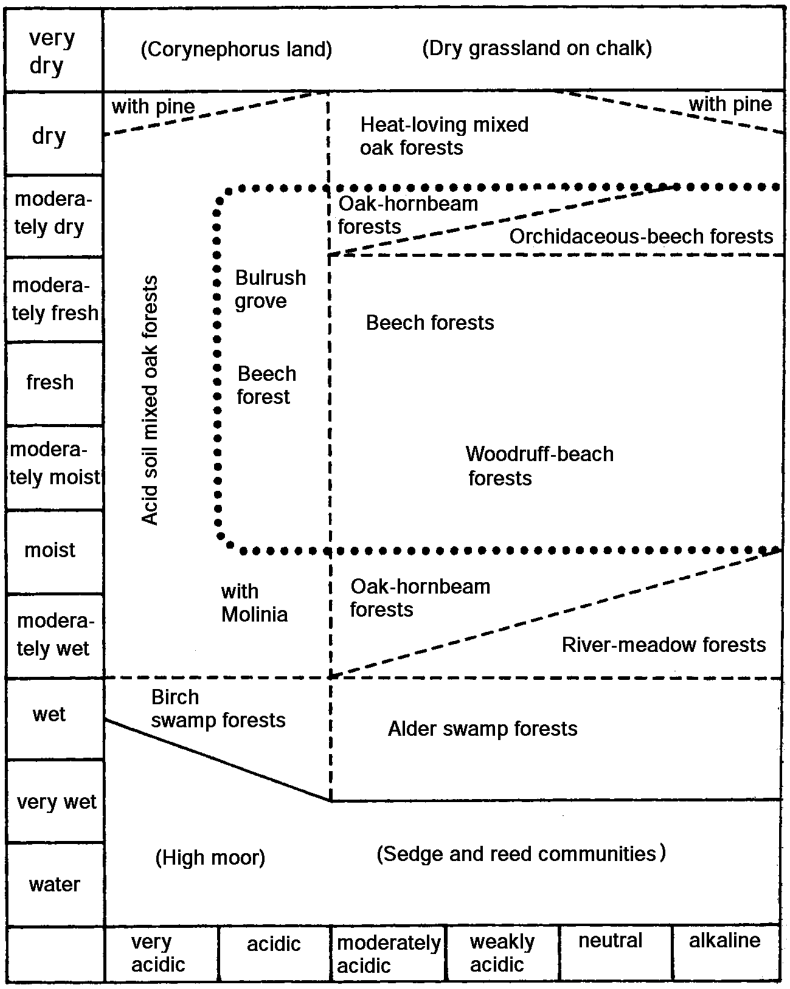
7.1 Demands on the location of communities in deciduous forests

Soils are locations for higher plants. These root in the soil, from which they take up oxygen for root respiration, water for turgidity, transpiration and photosynthesis, as well as mineral nutrient elements for the production of organic substances. The site factors which are of consequence for plant growth are predominately dependent upon the available space for roots, the water, air and heat balance, as well as the nutrient balance.
Because of the adaptability of living things (plants) to their environment, there is a more or less close connection between plant community and soil. In forestry, the cultivation of types of trees suited to the location is strived for, i.e. trees which are adapted to the particular location. Examination of the water balance (Experiment 8-11) and also the soil pH (Experiment 14) enable the relationship between the location factor soil and the deciduous forest community at that site to be found, or the "site adaption" of the predominating types of tree to be checked (see Fig. 7.1).

7.2 Site evaluation with indicator values

As plant communities are dependent on certain location factors, it is possible to go the other way around and draw conclusions on the conditions at the location from their

Fig. 7.1: Ecogram of a Central European deciduous forest community



occurrence. ELLENBERG's indicator values are a possibility for the evaluation of locations. They are numerical values which show the relationship between plants and their abiotic location factors in abbreviated form.
To produce the relationship between soil factors and indicator plants, water balance (*Experiment 8-9*), pH value (*Experiment 14*) and nitrate content (*Experiment 16*) are compared with the indicator values of the soil vegetation (soil moisture F, soil reaction R, soil nitrogen supply N). These can be taken from the appropriate literature. Most meaningful is a comparison of two to three forest locations which differ in respect to vegetation and soil consistency.
For the evaluation of the vegetation survey, the ecological behaviour of the individual types is referred against the location factors *moisture (F), soil reaction (R)* and *nitrogen supply (N)* on a scale of 1 to 9 and compared with the measured soil values.

Table 7.2: Explanation of symbols for the indicator values

F = Moisture number

1 Indicator of great dryness, viable at locations which often dry up and restricted to dry soils.
2 Is between 1 and 3
3 Indicator of dryness, more often occur on dry soil than on fresh soil, not on wet soil
4 Is between 3 and 5
5 Indicator of freshness, mainly on moderately moist soil, not on wet soil or soil which often dries up
6 Is between 5 and 7
7 Indicator of moisture, mainly on well aerated soil, not on wet soil
8 Is between 7 and 9
9 Indicator of wetness, mainly on soil which is often sodden (low air content)
10 Indicator of changing water, aquatic plants which can endure long periods without water coverage

R = Reaction number

1 Indicator of strong acidity, never occur on weakly acidic to alkaline soil
2 Is between 1 and 3
3 Indicator of acidity, mainly on acidic soil, never in neutral soil
4 Is between 3 and 5
5 Indicator of moderate acidity, seldom occur on strongly acidic or on neutral to alkaline soils
6 Is between 5 and 7
7 Indicator of weak acidity to weak alkalinity, never on stronly acidic soil
8 Is between 7 and 9
9 Indicator of bases and lime, always on lime-rich soil

N = Nitrogen number

1 Indicator of lowest-nitrogen locations
2 Is between 1 and 3
3 More frequently at locations low in nitrogen than at moderate to rich ones
4 Is between 3 and 5
5 Indicator of locations moderately rich in nitrogen, seldom at low or rich ones
6 Is between 5 and 7
7 More frequently at nitrogen-rich locations than at poor to moderate ones
8 Strong indicator of nitrogen
9 Concentrates at locations with an over-abundance of nitrogen (cattle thallophyte, pollution indicator)

8. Soil is a habitat for animals

8.1 The diversity of soil life

The apparently "lifeless" soil is in fact filled with a multitude and diversity of life, which is called edaphon. Most of the soil organisms live in the upper centimeters of the soil. A first differentiation can be made between soil fauna and soil flora, further according to size, as megafauna, macrofauna, mesofauna and microfauna (see Fig. 8.1).

Fig. 8.1: Classification of soil animals according to size

Megafauna (> 20 mm)	**Macrofauna** (2-20 mm)	**Mesofauna** (0,2-2 mm)	**Microfauna** (< 0,2 mm)
Mammals Amphibians Reptiles Earthworms	Chaetopods Snails Spiders Slaters Diplopoda Beetles / -larva Diptera larva Earwigs	Wheel animals Tardigrada Nematoda Mites Spring-tails False scorpions	Unicellelar organisms Amoeba

Bacteria, fungi, algae and animals in the soil can be differentiated according to taxonomic categories. For animals, Protozoa, Nematoda, Annelida, Mollusca and Anthropodes. Besides the small animals, the edaphon, there are also larger animals which live in the soil, such as moles and voles, as well as numerous animals which use the soil to hibernate (dormouse, toad, lizard, slowworm, badger), to raise offspring (rabbit, fox), as larder (squirrel, hamster) or to sleep. The vertebrates which live permanently or temporarily in soil (amphibians, reptiles, mammals) are generally not included in the edaphon.

Soil organisms are suited to their habitat in diverse ways, their size to the narrow pores between the soil particles, their food requirements to the decomposition of organic matter, their senses to the dark and moistness.

Earthworms: The earthworm is of particular importance among the soil organisms. It not only seves to decompose organic matter, but also contributes to the mixing of the soil and to aggregate formation. It draws remains of plants into the soil, and the tunnels it makes assist in aeration and drainage. According to a farmer's rule of thumb, the total mass of the earthworms in an area of 1 hectare pasture land corresponds approximately to that of three cows grazing on the same land. The number of earthworms is dependent on the amount of dead plant parts.

Spring-tails: Spring-tails belong to the wingless insects. They are small (0.25-10 mm) and live in the litter layer or in the cavities in deeper layers of soil. Most kinds have a spring-furca on their hind body. This is clapped to the front, up against the abdomen in the resting posture, but it whips back when disturbed and the insect springs away. Spring-tails feed on algae, bacteria and fungi hypha as well as on remains of faecal material. Large spring-tails gnaw openings and passages in leaf tissue.

Mites: Mites belong to the Arachnida, and are primary decomposers, secondary decomposers or predators, according to kind. Horned mites live in humus-rich topsoil, in moss carpets and decaying tree stumps. Some horned mite kinds gnaw leaves as primary decomposer, others live as secondary decomposers on algae, lichen and fungi hypha. Predatory mites hunt small animals in the layer of litter they live in or on.

8.2 Decomposition of plant litter by soil animals

The probably most important function of the life of the soil in the ecosystem is the decomposition and remineralization of organic substance, and so the return of mineral substances into the nutrient cycle. In an ecological sense, edaphon belongs to the destructors and reducers (decomposer, saprophyte).

Primary decomposers, such as earthworms, slaters, mites, diplododa, springtails and larva of various midges, feed on dead plant parts. Bacteria and fungi live on the excrement of these organisms. Other bacteria and fungi also act directly on the decomposition of the dead plant. After a chain of decomposition processes, small molecular substances and ions are finally obtained, and these can be newly taken up by plant roots. An army of predatory soil organisms form the end of this complex food structure. The multitude of life in soil can be ascertained at their location *(Experiment 18)*.

The effectiveness of the decomposer is on their part dependent on the soil factors, e.g. on how high the temperature and moistness is, on the type of plant material, on the soil pH etc.. For example, the decomposition process for spruce needles takes several years, whereas the leaves of most deciduous trees are decomposed after a single year. Decomposition is completed within a few months on a field having an optimal pH value, good aeration and sufficient water content.

An acceleratory effect is given by:

High temperatures, a continuous supply of O_2, a high N content in the litter, easily decomposable C compounds.

An inhibitory effect is given by:

Low temperatures, lack of O_2, low N content in the litter, difficultly decomposable C compounds (e.g. lignin, tannin).

The relationship between the decomposition processes – which are mirrored in the soil horizon *(Experiment 1)*, the humus content *(Experiment 6)*, the type of humus *(Experiment 7)* and the soil organisms *(Experiment 19)* – and the soil factors – water capacity *(Experiment 9)*, soil compression *(Experiment 12)* and soil pH *(Experiment 14)* – can easily be established from the corresponding measurements.

Room for notes

9. Soil fertility

The ability of soil to serve as a location for plants and to produce yields of crops is named the fertility, profitability or productivity of the soil. It is conditioned by the entirety of the physical, mineralogical, chemical and biological properties of the soil.

The most important dimensions of soil fertility are persistence of yield/expenditure, small variations in yield, dependence on the weather, quality of the yield, wide growth spectrum, buffering of immissions. These characteristics of *soil fertility* are dependent on numerous soil properties, such as:

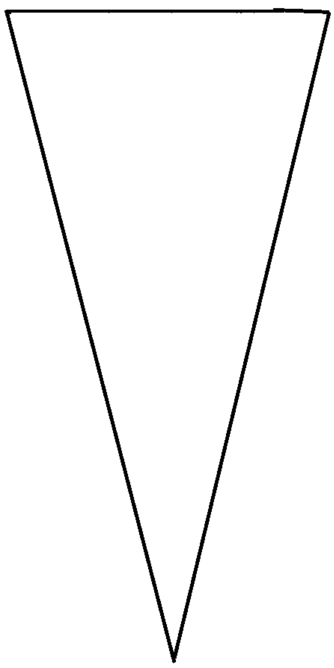
- Texture, which influences the water, air and nutrient balance, as well as cultivation and root penetration.
- Thickness of the nutrient rich soil layer.
- Degree of acidity (pH) as indicator for lime status, possible soil activity and the availability of numerous nutrients.
- Content of available nutrients and reserves of nutrient.
- Nutrient holding capacity (sorption property) for loose storage, adsorbable nutrients, buffering against excess, protection against leaching.
- Humus content with influence on life in the soil, holding capacity for water and nutrients, nutrient content and soil structure.
- Favourable soil structure (loose, crumbly).
- Biological activity of the soil.
- Freedom from foreign substances (or harmful amounts of them), pathogens and pests.

These soil properties which condition the soil fertility differ in their stability, or lability (Table 9.1). The texture (kind of soil) is quite a stable soil property, but can, however, suffer loss by erosion, which can only be made up for to a limited extent by new formation from weathering. The soil reaction (measured as pH) has average stability. The soil acidification resulting from natural causes and from utilization can be acted against by liming. The structure and the biological activity are quite labile soil properties (see Table 9.1).

It can be concluded from the stability/lability of the soil properties, that soil fertility is not a permanent location factor, but must, as a complex of more or less stable/labile soil properties, be continually newly created. The aim of every soil management, whether on a garden scale or in agriculture, must therefore be the utilization of the soil with simultaneous maintenance and increase of soil fertility.

Soil fertility so represents a certain framework for the expected yield. Within this framework, however, there is a large scope for suitable measures to optimize the yield. The activity of the farmer is therefore directed towards extensive utilization of the non-controllable location factors, and to influencing the controllable factors positively for the yield.

Table 9.1: The stability of soil properties which govern soil fertility

Property	Stability	Loss	Profit
Soil texture		Erosion	(Weathering)
Depth		Erosion, compression	Melioration
Soil acidity		Extraction, washing out, immission	Liming
Nutrient storage/ follow up supply		Yield, washing out, mineralization	Fertilizing
Humus content		Erosion	Rotation of crops
Structure		Compaction	Melioration
Biological activity		Harmful substances	Minimal soil cultivation

10. Soil evaluation and soil number

The quantitative evaluation of soil used for agriculture or gardening with respect to its potential fertility in Germany is carried out using the so-called field evaluation frame. The basis of this is the "Law on the evaluation of cultivated soil", which was passed in 1934 and supplemented in 1965. It is the basis for taxing agriculture, for practical soil utilization planning, for loans and for compensation etc..
The soil evaluation is carried out by officially appointed land evaluators according to a relatively simple evaluation scheme, which determines a soil number for a field, from the soil texture, stage of soil condition and type of origin. Soil numbers are relative numbers, which set the yield potential of that particular soil in relation to the most fertile soil (the black earth of the Magdeburg plain, which is set as 100).
The kind of soil expresses the particle size composition of the soil, i.e. the relative amount of sand, silt and clay. Each particular combination determines the water balance and nutrient balance of the soil and so its fertility (see Table 10.1).

11. Fertilizing plan and cultivation of the soil

It is customary to carry out regular examinations of the most important soil factors of soils which are used for agricultural or gardening purposes, so that a plan can be made for the cultivation and fertilization of the soil for the coming or future years. The examinations are generally carried out in spring, and are offered by agricultural offices and institutes. You can, however, carry them out yourself, with relatively simple means.
The working scheme for such a soil examination (see the Worksheet), lists the appropriate experiment, as described in Chapter V, for each soil factor (first column); the values determined can be entered in the Worksheet. The second column contains notes on the evaluation of the values determined from the point of view of the soil fertility; the corresponding Tables and explanations are given in the following Chapters, together with notes on the appropriate measures for cultivation of the soil and fertilizing it, which can be entered in the third column.

Table 10.1: Soil numbers in dependence on the soil texture

Soil texture	Abbreviation	soil number [1) 2)]	Average value of the soil number [3)]	
Sand	S	7 - 44	23	
Weakly loamy sand	Sl	11 - 53	30	sand soil
Loamy sand	lS	12 - 71	39	
Strongly sandy loam	SL	16 - 81	48	
Sandy loam	sL	18 - 92	55	loam soil
Loam	L	19 - 100	61	
Clayey loam	LT	17 - 91	55	clay
Clay	T	14 - 74	44	

1) According to the type of origin and the stage of condition of the soil
2) Gives the goodness of the soil, best soil = 100
3) Average value from type of origin and 7 stages of condition

Worksheet: Examination and management of soil

Examination:	Evaluation:	Measure:
Soil texture (Exp. 5):	Table: Soil properties, average soil number	Cultivation of the soil, means for soil improvement:
Humus content (Exp. 6):	Table: Evaluation of humus	Humus management:
Soil pH (Exp. 14):	Table: pH target	Liming:
Lime content (Exp. 15):	Table: Lime target	
Nitrate content (Exp. 16):	Table: Nitrogen requirement	Nitrogen fertilizing:
Soil tilth (Exp. 13):	Water balance/ Air balance	Fertilizing, cultivation:
Soil compaction (Exp. 12):	Water balance/ Air balance	Fertilizing, humus management:
Life in the soil (Exp. 18):	Qualitative evaluation	Humus management, cultivation of the soil:

12. Soil texture, humus and water balance

12.1 Soil texture

The soil texture is a factor which has a decisive influence on the soil fertility. In addition, it is also a component of the pH target for a soil, alongside the humus evaluation (Experiment 5).

Evaluation of the soil texture

A *sandy soil* consists predominately of grains of quartz (SiO_2), which is among the minerals which are most difficult to weather. Precipitated water sickers quickly through the relatively large pores. The nutrient salt content of sandy soil is low, so that it is not normally used for agricultural purposes. When it has a fine earth content of up to 20%, it is called loamy sand or sandy loam. Undemanding cultivated plants such as rye, oats, potatoes, carrots and asparagus can flourish in this.

The clay content of *loam soil* is between 20% and 50%. The holding capacity of loam soil for nutrient salts and water is favourable. Loam soils belong to the soils giving the highest yields. Wheat, sugar beet, rape and barley give top yields here.

Clay soils have a clay content of more than 50%. The topsoil structure of a clay soil can be improved by liming and with organic manure. A clay soil which has had its topsoil so improved can more quickly take up water and also store it better. It has a high air content and roots can penetrate it easily. Such clay soils bring highest wheat yields.

Measures for improving the soil texture

With *sandy soil* it is necessary to bring fine clay minerals or similar solid components (e.g. humus) into the soil. This can be achieved by bringing in bentonite (agricultural bentonite), whereby it is sufficient to add 150g/m^2 to the soil once a year, if possible in spring, and to lightly work it in. The same effect, plus other positive effects, can be achieved with compost. Uncontamined compost can be brought into such soils in any amount, as long as they are not wet or too acidic. Coverage of the soil with green manure plants or mulch is further recommended for light soils, as this prevents a drying out of the soil.

Loam soils are ideal to cultivate in the ideal case and are an ideal location for any kind of agricultural utilization. With regard to the improvement of soil fertility, this depends on whether the middle soil tends more towards sandy or clay soil. In each case, the measures described here are to be taken in a more moderate fashion. An increase in the life in the soil by gentle soil cultivation, soil coverage and the addition of compost has a favourable effect in either case.

Clay soils are identifiable by their high clay or loam content. Whereas sandy soil lacks fine clay particles, heavy soils have a lack of coarse sand particles. It can be derived from this, that to improve a heavy soil with respect to mineral soil particles, one must proceed in exactly the opposite way as to with a light soil. This means that heavy soils can be improved by bringing in sand. For this, grain size 0/3 should be used, which is building sand and so easy to obtain. All types of humus material, i.e green manure plants, organic manure, horse dung with plenty of straw, compost, cattle dung with plenty of straw and other types of dung, can be used to decisively improve the structure of heavy soils.

Fig. 12.1: Measures to improve soil fertility

Soil	Sandy soil	Loam soil	Clay soil
Cultivating measure	Bring in compost	Acc. to sand/clay content	Bring in sand
	Bring in bentonite		Bring in compost
	Soil coverage		Foster earthworms
	Green manuring		intercropping

12.2 Water balance

Soil water and soil air are highly dependent on the soil texture and the humus content (see the following chapter). They have an effect on nearly all processes occurring in the soil, and so also on soil fertility: Soil water covers the water requirements of the plants, soil water dissolves and transports nutrients (they can only be taken in by plants in dissolved form), soil water participates in soil weathering and so in the liberation of nutrients, soil water is a basic necessity for life in the soil and so also for the formation of humus, soil air is a prerequisite for the respiration of plant roots and microorganisms. The water balance can be determined *(Experiment 9/10)* to supplement and clarify the importance of the soil texture.

Evaluation of the water balance and air balance

Sandy soils have mainly large (air-filled) pores, and so tend to be deficient in water. Clay soils have mainly small (water-filled) pores, and so tend to be deficient in air. A balanced relationship between large and small pores is therefore necessary for a soil to have a positive water and air balance. Loam soils have such a balanced relationship, whereas sandy soils tend to be dry and clay soils tend towards stagnant water.

The water-holding capacity of a soil can also be estimated from the soil texture and the humus content. These can be also be used as a check on values of it which are measured (see Table 12.2).

Measures for improving the water balance and air balance

The balance of water and air is considerably dependent on the soil texture (sand, silt, clay), the humus content and the soil structure of the soil. The latter is for its part dependent on the activity of life in the soil, in particular of earthworms. The measures described can therefore be taken to improve the water and air balance. Further to these, sufficient watering should be ensured for sandy soil. The watering must be carried out regularly, as sandy soil cannot hold water. With clay soils, it is important to avoid treading on bedding areas as this causes soil compaction.

12.3 Humus management

Humus acts positively on the soil in many ways and therefore has a decisive influence on the fertility of the soil *(Experiment 6)*:

- Humus improves the soil structure, both directly by its loosening up effect on heavy soil and indirectly by being a food for the soil organisms whose activity loosens the soil.
- Humus promotes the aeration of the soil. The improved crumb structure results in larger pores, and these result in an improvement in the supply of oxygen.
- Humus improves the water balance in the soil. On the one hand, it holds water like a sponge, which is particularly important for sandy soil; on the other hand, through its loosening of the soil, it causes sufficient sickling through of water to prevent the presence of stagnant water, which is particularly important for clay soil.
- Humus increases the temperature of the soil, as it absorbs heat energy from the sun better because of its dark colour. The soil gets warm quicker, which is of particular importance in spring.
- Humus supplies nutrient, as the so-called nutrient humus is decomposed to nutrients by soil organisms.
- Humus can store nutrients and give them up to plants when they are required. This is of particular importance for soil with a low clay content.

Evaluation of the humus content

A soil which is used for gardening or agriculture should contain at least 2-4% humus. Higher values are even more favourable. It is not until extreme values are reached (approx. 15%), that unfavourable soil properties (wetness, acidity) are found because of a slowing in the decomposition of the humus.

Table 12.2: Water-holding capacity of various soils in per cent by volume

	Slightly sandy or sandy soil	Loam soil
Low in humus	5 %	20 %
Humous	11 %	25 %
Rich or very rich in humus	25 %	38 %

Measures to increase the humus content
— Vegetation cover the whole year round (crop rotation)
— Working in of harvest residues (land composting)
— Green plant manuring
— Bringing in organic manure (compost etc.)

The point of a humus-increasing soil management is, however, that the bringing in of organic matter alone does not bring the wanted success. A build-up of humus does not take place until the corresponding humus-forming microorganisms in the soil are activated by the organic matter.

13. pH and lime fertilization

13.1 The pH of the soil

The pH is an expression of the acidity of the soil; it is a measure of the content of hydrogen ions in a liquid (here the soil solution).

A neutral to slightly acidic pH of the soil (pH 6 to 7)
— promotes the biological activity of the soil and so the humus conversion,
— promotes the solubility of nutrients,
— hinders the liberation of poisonous aluminium ions,
— and promotes plant growth, as most crops flourish best at a neutral to slightly acidic pH.

Measurement of the soil pH (Experiment 14)

The pH is the only characteristic chemical quantity of the soil which can be sufficiently accurately measured with simple means. To be sure, as a result of the sample taking (change in structure) and the addition of liquid (wetting, change in the salt composition, lack of oxygen), considerable changes in the pH occur in the soil solution. Because of this, the common procedures measure a reproducible value, based on convention, rather than the actual pH of the soil (in as much as it is at all possible to measure this).

The following standarized methods have crystallized out in soil science for the measurement of the soil pH:
— pH measurement in H_2O (pH H_2O)
— pH measurement in 1 N or 0.1 M KCl solution (pH KCl)
— pH measurement in 0.1 M $CaCl_2$ solution (pH $CaCl_2$)

As each of these procedures gives a different pH value, the solvent used should be stated alongside the pH. A pH (H_2O) measurement gives a pH which is approx. 0.5 higher (i.e. lower hydrogen ion concentration) than the other procedures, as only the freely mobile, dissociated H ions are determined. A pH (KCl, $CaCl_2$) measurement gives an 0.1 to 0.4 lower pH (i.e. higher hydrogen ion concentration) than the H_2O measurement, as, because of the addition of salt (KCl or $CaCl_2$), cationic acids such as Al ions as well as H^+ ions are liberated from the exchangers and pass into the soil solution. The $CaCl_2$ solution measurement is customary in Germany.

Evaluation of the soil pH

The Society of German Agricultural Examining and Research Institutes gives the following guidelines for pH values which are to be strived for in agricultural mineral soils (up to 4% humus, see Fig. 13.1).

When the pH of the soil is in the optimal region, then only a maintenance liming is required (see the next Chapter). When the measured pH is clearly below the optimal value, then a restorative liming is necessary. The orientatation is the pH target for the particular soil.

Measures for improving the soil pH

The following measures can be taken (when the pH is too low):
— Liming the soil (see the next Chapter)
— Use of a neutral to basic manure (e.g. nitrogen)
— Use of less acidic litter for the compost

Fig. 13.1: pH targets ($CaCl_2$) for mineral soil (up to 4% humus)

Soil texture	Arable land		Pasture land	
	pH-target	optimal pH	pH-target	optimal pH
Sand (S)	5.5	5.3 - 5.7	5.0	4.8 - 5.2
Loamy sand (lS)	6.0	5.8 - 6.2	5.5	5.3 - 5.7
Sandy loam (sL)	6.5	6.3 - 6.7	6.0	5.8 - 6.2
Loam, clay (L. T)	7.0	6.9 - 7.2	6.2	6.0 - 6.5

13.2 Soil improvement with lime

The natural chalk content of a soil is determined by the parent rock from which it was formed. Some soils are naturally low in chalk, others have become depleted of it in the upper soil horizon (Experiment 15). The latter situation results predominately from the natural and man-caused introduction of acid into the soil, or from the intensive utilization of the soil. Because of this, soil used for arable farming must be regularly limed. A differentiation is made between two types of lime fertilization, maintenance liming and restorative liming.

Maintenance liming is carried out to replace the yearly loss of lime. In this case, a preventive, relatively small annual quantity of lime of 20 to 50 g/m^2 CaO is used, corresponding to the loss of lime.

When the lime requirement determination shows that a larger quantity of lime is required, one speaks of a one-off restorative or melioration liming. The purpose of the restorative liming is change a strongly acidic soil in the direction of a neutral pH (= 7) as quickly as possible. This can occur when a garden is newly planted or when liming has been neglected for a long time.

Lime is first and foremost a soil fertilizer. The favourable effect it has on plant growth is based in particular on its improvement in the chemical, physical and biological properties of the soil. Compared to this, its value as a plant nutrient is far less important.

— Lime regulates the soil pH: Lime neutralizes soil acids and so ensures a favourable soil pH. The addition of lime increases the soil pH.
— Lime improves the soil structure: The calcium ions bind clay and humus particles to larger aggregates. In this way, the share of larger, air-carrying pores is increased. The stability of the pores and the resistance of the soil to compaction increase. This acts favourably in reducing soil erosion, on the water and air balance, on plant growth and so on the nutrient uptake of plants.
— Lime fosters life in the soil: The regulation of the water, air and, indirectly, the heat balance as well as the soil pH by lime promotes the activity of microorganisms and soil animals. This results in an intensification in life building (the sticking-together of soil particles by soil organisms) and in humus formation.

Lime requirements and recommended fertilization

Soils are divided into lime requirement classes in the following Table, according to the kind of soil and the pH measured. When the soil has been found to be of sandy loam type (sL) and a pH of 5.8 is measured for it, then the soil needs liming (see Fig. 13.2).

When the appropriate lime requirement class has been determined, then the amount of lime required for it can be found in Fig. 13.3.

Fig. 13.2: Lime requirement classes

Soil structure	high lime requirement	Requires lime	Lime supply is OK
Light soil (S, uS)	pH below 4.9	pH 5.0-5.7	pH above 5.7
Medium soil (LS, sL, U)	pH below 5.5	pH 5.6-6.3	pH above 6.3
Heavy soil (L, T, tU)	pH below 5.7	pH 5.8-6.9	pH above 6.9

Fig. 13.3: Fertilization recommendation in kg CaO/100 m^2 (= dt CaO/ha)

Soil structure	high lime requirement	Requires lime	Lime supply is OK
Light soil (S)	5 - 10 kg annually	3 - 5 kg annually	3 - 5 kg every 2 years
Medium soil (LS), (sL)	10 - 20 kg annually	5 - 10 kg annually	6 - 12 kg every 3 years
Heavy soil (L, T)	20 - 40 kg annually	10 - 20 kg annually	15 - 20 kg every 4 years

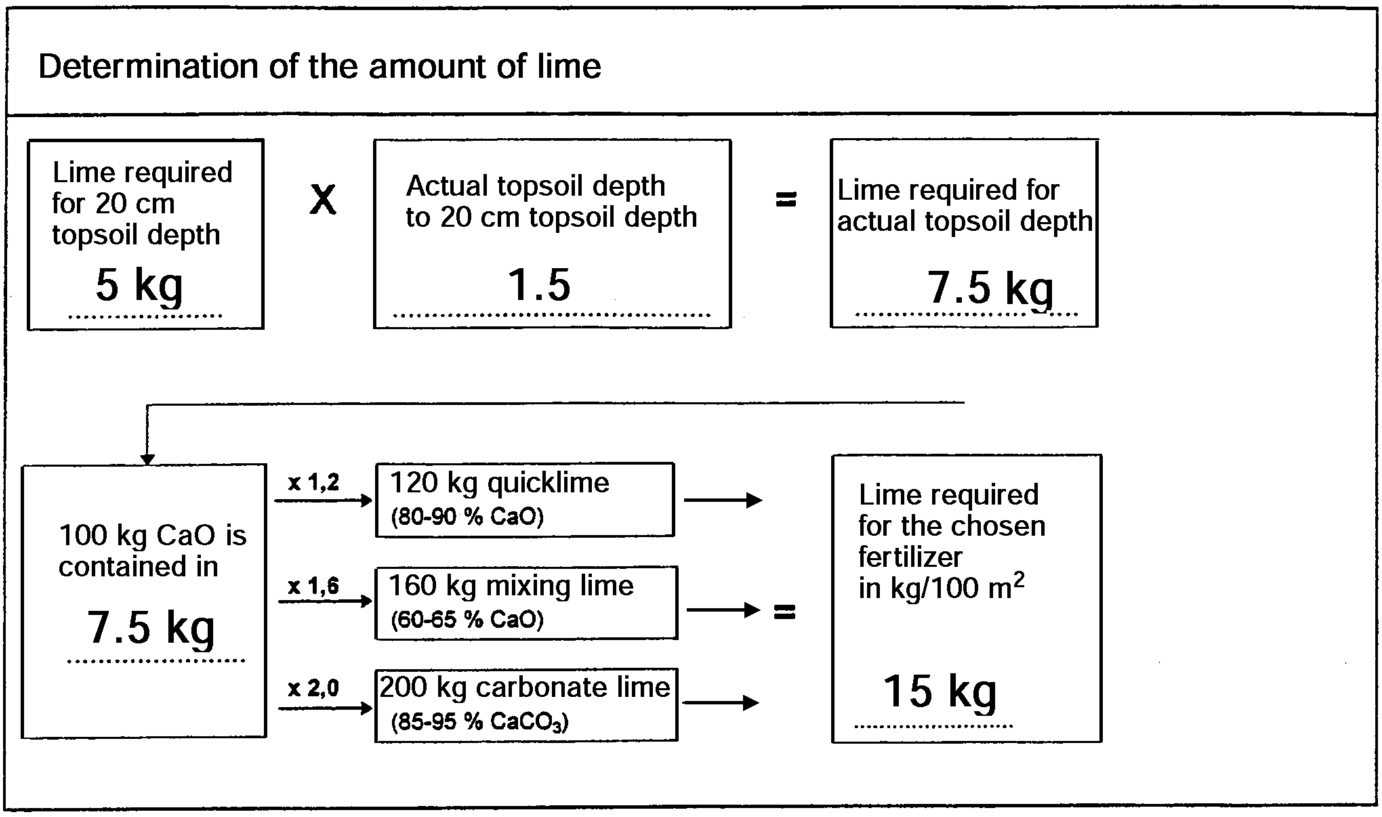
Which sort of lime for which soil?
Lime and lime can be two different things! There are namely many different sorts of lime: quicklime, metallurgical lime, algar lime etc.. The most important criterium for the correct choice of the lime fertilizer is the different speed of action of the lime in the soil.
For light, low-clay soil choose slowly acting lime: ground-up limestone or dolomite, slag lime, converter lime.
With increasing clay content, i.e. with medium to heavy soils, select quick acting lime: Quicklime, slaked lime, mixing lime and carbonate lime.
With respect to their neutralizing effect, the lime fertilizers named above only differ on a long-term, or hardly at all. When choosing a fertilizer, the accompanying ingredients should also be taken into consideration.

Determination of the quantity of lime
When the lime requirement and the fertilizing recommendation have been found, then the actual amount of lime which is to be brought in must be calculated. This is dependent on the depth of the topsoil and the sort of lime fertilizer.
The lime requirement stated by the Testing Laboratory or in the Table always relates to to topsoil depth of 20 cm. If this is deeper, then the value must be calculated up to the actual depth.

You now have the amount of pure lime (CaO) which should be brought into your soil. As commercial fertilizers do not consist of 100% lime, however, a further calculation is required. As a rule, a "reference basis for lime action in % CaO" is given on commercial fertilizers. After you have chosen the appropriate fertilizer, enter the value given in the equation.

Carrying out liming
Lime fertilizers can be used at any time of year, as long as the weather and the crops allow it. The best liming effect is achieved when the lime is intensively mixed into the soil. A quick and even distribution is necessary for quicklime and slaked lime in particular. A separation in time between lime fertilization and nitrogen fertilization is always necessary when the nitrogen is in the form of ammonium. This is also valid for stable dung and liquid manure. Otherwise, at higher pH values and with a good supply of water, considerable losses of nitrogen can occur. A waiting period of 14 days has been found favourable, when the lime is not worked into the soil in the meantime. When the lime is worked into the soil, the nitrogen fertilization can be carried out directly after liming.

Fig. 13.4: Determination of the amount of lime (example for 30 cm humus depth and fertilizing with carbonated lime)



14. Nitrogen fertilization

Nitrogen is often the limiting nutrient in a soil, which is also removed from the nutrient cycle in plant production by harvesting of the nitrogenous crop. Nitrogen must therefore be added to garden soil in organic or mineral form. Nitrogen in the form of nitrate (NO_3) is not bound (fixed) by the soil exchangers, and is so easily washed out, and frequently appears in drinking water as unwanted burden. In addition, nitrate can be taken up by plants in (too) high concentrations, without being converted to an organic form (amino acids). It is then present in the corresponding food as health hazardous nitrate.
The aim and problem of all practical fertilizing measures is therefore the same. Plant-available nitrogen must be supplied in the required quantity and at the right time, so that on the one hand the yield potential of the cultivated plants can be utilized as much as possible, and on the other hand uneconomical or environmentally polluting and health hazardous nitrate concentrations in foodstuffs are avoided. This is valid, independent of the particular form, for practically all nitrogenous fertilizers, including organic manures.

Determination of the N fertilizer requirement (Experiment 16)

To produce economically favourable and healthy foodstuffs, it is necessary to determine the particular nitrogen fertilizer requirement for the plant in dependence on the soil. Whereas previously the nitrogen withdrawal number of plants was mostly used for orientation on the amount of fertilizer to be added to the soil, this amount is nowadays usually estimated by means of the so-called N min method (N min = abbreviation of mineral nitrogen), in which the nitrogen present in the soil is included in the calculation.
The N min method can be expressed simply by the following formula:

N fertilization (kg/ha) = Nitrogen required by the plant
– N min reserves in the soil

The principle of the N min method can be demonstrated by an example of its use for spinach:

Plan value in spring (= N amount required for highest yield):	120 Kg N/ha
minus N min reserves (measured in February in 0-60 cm depth):	-70 kg N/ha
Required N fertilization in spring:	50 kg N/ha

When the required 50 kg N/ha are added as fertilizer, then the soil is filled up to 120 kg N/ha and so attains the plan value for the N content, which guarantees the highest yield for spinach.
The depth of soil which is taken into consideration is that to which the plant roots can go, and is so dependent on the plant species and on the soil. This comprises a depth of 0-90 cm in deep soil, and of 60 cm or less in shallow soil. It has been proved to be useful to divide the soil profile into 30 cm fractions. The separate examinations allow judgement to be made, on how the N supply is distributed through the soil, e.g. near to the surface or deeper, and gives more exact values, as the nitrogen content is not uniform over the whole soil depth.
For sowing or planting, it is sufficient for all cultures to examine the topsoil (0-30 cm) only. The large soil auger is first required later, when the roots of the particular plant species have reached the second or third soil layer. The two or three soil layers (0-30 cm, 30-60 cm and 60-90 cm) should be collected separately in appropriately labelled buckets. Sample taking or measurement should be made shortly before the first N fertilization at the vegetational start, in March at the latest.

Simplified N min method: The taking of the soil sample with a soil auger is usually not particularly difficult for the first (0-30 cm) and second (30-60 cm) layers. It is usually a problem, however, in the case of the third (60-90 cm) layer. When, for various plant species such as beet, brussel sprouts and heads of cabbage, this third layer must be examined, experiments have shown that a simplified procedure can be used:

1. Examination of 1st layer (0-30 cm):		a (kg N/ha)
2. Examination of 2nd layer (30-60 cm):		b (kg N/ha)
3. Addition:	(a + b) =	c (kg N/ha)

Fig. 14.1: Rooting depth/depth and sampling

30 cm	Peas	Lettuce	Radishes	Iceberg lettuce
60 cm	Cauliflower	Endive	Turnip cabbage	Celery
	Beans	Strawberries	Potatoes	Tomatoes
	Broccoli	Spring spinach	Leek	White cabbage (early)
	Chinese cabage	Curly kale	Beetroot	Onions
90 cm	Apples	Maize	Brussel sprouts	White cabbage
	Corn		Asparagus	

When the N min values for the first and second layer are added together (= c) and doubled (= 2c), then an approximation of the N min potential over all three layers is obtained. This simplified procedure has been proved in practice. The margin of error is usually less than ±30 kg N/ha.

Nitrogen requirements of cultivated plants

The nitrogen requirement of a particular cultivated plant must be taken from corresponding agricultural Tables. The amounts of nitrogen given (plan values) are for "empty" soil. The N min reserves must therefore be taken into consideration.
The values given must possibly be adjusted to local conditions. Influencing factors are, for example, for open land: the humus supply, distance apart of plants, length of time of cultivation, soil texture and the expected yield (see Fig. 14.2).

Procedure for nitrogen fertilization

For a targeted nitrogen fertilization, i.e the addition of fertilizer according to the requirements of the plants, the following factors must be observed:

1. The size of the fertilizer requirement
2. The type of fertilizer
3. The amount of fertilizer (in dependence on the fertilizer requirement and type of fertilizer)
4. The time to start fertilization and distribution over time.

The size of the fertilizer requirement is calculated from the difference between the N requirement of the plants and the N reserves in the soil. The type of fertilizer should be tuned to the effect of their acid character on the particular pH of the soil. This means that when the pH already lies in the acidic region, then no acidifying fertilizer should be used (see Fig. 14.3).

Fig. 14.2: Nitrogen requirement of cultivated plants

Vegetable	N-requirement (kg/ha)	Vegetable	N-requirement (kg/ha)
Apple	80	Fennel	180
Asparagus	100	Turnip cabbage	180
Beetroot	160	Leeks	140
Black salsify	160	Lettuce	70
Brussel sprouts	180	Onions	180
Cabbage	300	Parsley	160
Carrots	160	Peas	30
Cauliflower	140	Potatoes	150
Chicory	80	Pumpkin	100
Chinese cabbage	180	Radish	200
Chives	200	Radishes	50
Corn (sweet)	150	Rhubarb	200
Corn lettuce	50	Savoy cabbage	120
Cucumber	150	Spinach	120
Curly kale	120	Tomatoes	150
Dwarf beans	100	White cabbage	120
Endive	120	Zucchini	200

Fig. 14.3: Acidifying effect of nitrogen fertilizers

Very strongly/strongly acidifying:	Ammonium sulfate	Loss of 3 kg CaO per kg N
	Ammonium sulfate and nitrate	Loss of 2 kg CaO per kg N
Moderately acidifying:	Urea	Loss of 1 kg CaO per kg N
	Ammonium nitrate	- „ -
	Ammonia	- „ -
Neutral/weakly acidic	Calcium ammonium nitrate	Loss of 0.4 kg CaO per kg N
Alkaline:	Calcium nitrate	Win of 1 kg CaO per kg N
	Calcium cyanamide	Win of 1.7 kg CaO per kg N

The amount of fertilizer is calculated in dependence on the fertilizer requirement and the type of fertilizer chosen in each particular case. As the various types of fertilizer do not consist of 100% nitrogen, and some of them do not act to 100% in the first year, the fertilizer requirement (expressed purely as nitrogen) must be converted to the amount of fertilizer required. To do this, enter the N fertilizer requirement (the difference between the N requirement of the plants and the soil reserves), as well as the N content of your chosen fertilizer, in the following equation. You will then have the actual amount of fertilizer which is to be used. If your fertilizer does not fully act in the first year, you must further convert the amount of fertilizer to take account of its less than 100% effectiveness.

As a rough orientation on the chronology of the distribution of the fertilizer: distribute about 1/3 to 1/2 of the total amount of fertilizer at the start of the vegetation period, the rest divided over 1-3 dates during the growing period.

Fig. 14.4: Calculation of the nitrogen fertilization (example: Spinach)

Calculation of the nitrogen fertilization

1. N min reserves of the 1stlayer (0-30 cm):	a	15 kg N/ha
2. N min reserves of the 2nd layer (30-60 cm):	b	15 kg N/ha
3. N min reserves of the 3rd layer (60-90 cm):	c	30 kg N/ha
N min reserves (0-90 cm) (a+b+c)	=	60 kg N/ha
Plan value in spring	=	120 kg N/ha
N fertilizer required (plan - reserves)	=	60 kg N/ha

N fertilizer required	x	100 % / N content of the fertilizer (%)	=	Amount of fertilizer in kg/ha (=g/10 m²)
60	x	100 % / 5	=	300

Amount of fertilizer (N) in kg/ha (=g/10 m²)	x	100 % / Effectiveness in 1st year (%)	=	Amount of fertilizer to be used in kg/ha (=g/10 m²)
300	x	100 % / 2	=	600

15. Soil tilth and soil animals

15.1 Tilth

"Tilth" is an old farmers word and the quintessence of a healthy, fertile soil, which is living and has an optimal crumb condition. Tilth is not a lasting soil property, but a condition in which the soil is in a state of readiness for its highest performance with respect to its diverse functions. Tilth must be brought about time and time again by the correct soil management measures. The tilth of a soil can be best judged by the stable crumb structure produced by organisms. The importance of tilth for the soil fertility;

— the crumb structure conditions a balanced relationship between large (air-filled) and small (water-filled) pores, and so ensures a positive water and air balance,
— the crumb structure avoids silting-up of the soil,
— the stable crumb structure reduces the carrying off of fertile soil (soil erosion),
— the loose crumb structure fosters an abundance of life in the soil,
— the loose crumb structure makes it easier for plant roots to penetrate through the soil, which results in a greater supply of nutrients for the plants.

Measures to improve the tilth

— The soil pH should be in the neutral region or correspond to the targeted pH for the soil.
— The life in the soil must always be supplied with sufficient organic material (root mass, compost, green manure plants, mulch).
— The soil should have a certain clay content (with sandy soil, add clay to the compost)
— The cultivation of the soil should be biologically purposeful. Life in the soil should be fostered, not disturbed and inhibited.

15.2 Life in the soil and soil fertility

The life in the soil, the edaphon, is decisively involved in the soil fertility. It returns nutrients to the nutrient cycle, mixes the soil, promotes the water and air balance and participates in the soil formation processes. The edaphon itself is, however, dependent on the soil as habitat.

Measures for promoting life in the soil

To promoting soil fertility, appropriate measures must be taken to ensure favourable living conditions for the life in the soil (see Abb. 15.1).

Fig. 15.1: Influencing ecofactors by culturing measures

Ecofactor	Culturing measures
– Loose soil structure,	– Gentle cultivation of the soil,
– organic matter as food,	– bringing in of organic matter,
– good supply of air and water, – favourable temperatures,	– soil coverage,
– neutral pH,	– liming,
– exclusion of harmful substances.	– exclusion of pollutants (e.g. pesticides).

Changes in soil are caused by over-shaping and sealing it off, by soil cultivation and compaction, as well as by removal of soil material by erosion. Burdening, or impact, of the soil takes place by changes in the soil and pollution with materials. The pollution with material results from fertilization, soil contamination and deposition of waste.

With regard to changes in the soil, *soil over-shaping* and *sealing off of soil* are processes which are mainly connected with the settlement activity of man. Soil-overshaping, i.e. the deposition and removal of soil, results from building projects as well as from winning mineral resources. The sealing off of soil results from coverage of the surface with water impermeable substances such as tar, concrete or buildings. In urban areas, up to 90% of the total surface are already sealed. This type of soil utilization is called surface usage, land utilization or soil mortality.

The *contamination of soil* results from dust from power stations and industry, as well as from acid rain, heavy metals, thawing salt, pesticides, organic compounds and radioactive substances. These pollutants are stored in the soil and accumulate there. In addition, they are taken up by plants – particularly when the storage capacity of the soil is exceeded – and so enter into the nutrient cycle. A part of the pollutants is washed into the ground water and drinking water. The extent to which soil can be loaded with pollutants is mainly dependent on the filtering anf buffering capacities of its exchangers, i.e. on the content of clay minerals and humus, as well as on its biological activity. The substances which most burden the soil are heavy metals, salts, acids and radioactive substances, as well as organic pollutants such as biocides, hydrocarbons and dioxin.

Heavy metals reach the soil as air pollutants or are carried into it with sewage sludge and compost, as well as with pesticides, and are held there by the soil exchangers. As they cannot be decomposed, their concentration in the soil gradually increases. A portion of the heavy metals passes permanently into the nutrient cycle via plant, animal and man. When the holding capacity of the soil is exhausted, the heavy metals increasingly pass into the ground water. They now reach the nutrient cycle and water balance in high concentrations, and so pollute nutrients and drinking water. In addition, the heavy metals held by the soil exchangers can be re-mobilized when acid enters the soil, e.g. on fertilization or with acid rain. When a certain concentration of heavy metals is reached, the cycle breaks down because of the poisoning of the soil, plants, animals and man.

Salts are brought into the soil by natural processes in coastal areas, and, in other areas, predominately with organic manure, precipitation and dust, as well as as thawing salt in the vicinity of roads. Increased salt concentrations lead to a change in soil properties and to impairment of life in the soil and of plants. While there is some relief in the burdening of urban areas because of the increasing doing-without thawing salt, there is still no reduction in the burden of salt in the vicinity of motorways.

Organic pollutants are brought into the soil with crop protectants, directly as soil herbicides, fungicides or pesticides, or indirectly from treatment of the crops themselves. It has been estmiated that more than 50% of herbicides reach the soil, directly or indirectly. Pesticides are bound to the soil exchangers and accumulate in the soil and in the life in the soil. Earthworms, for example, are now contaminated with DDT to a far larger extent than the soil. Organic pollutants such as chlorinated hydrocarbons, dioxin, also reach the soil via the air. A part of the organic pollution can be decomposed, at different rates, by life in the soil.

16. Soil compaction

Soil cultivation and soil compaction (Experiment 12) are burdens which occur from agriculture. They first cause a change in the soil structure, and as a result of this, impair the soil water and air balance *(Experiment 10)*. Besides this, the habitat of life in the soil is disturbed *(Experiment 18)*.

As a result of the sealing off and compaction of soil, and of intensive cultivation methods, the soil is exposed to stronger erosion, i.e. to removal of soil: fertile soil material is carried away by wind and water. The global extent of the karstification and formation of steppe is estimated to be 3-4 million hectare per year. Soil protection methods against erosion are the planting of shrubs, soil coverage the whole year over and gentle working of the soil.

A particular characteristic of soil in urban ecosystems, and its main difference to natural soil, is that the formation of the soil, its development and the development of the soil functions are decisively influenced by man. Town specific changes occur with increasing settlement activity, in particular in the rearrangement and removal of soil material (building projects), from compaction and sealing off of the soil, and by contamination with waste and pollutants. As a result, town soils often have a more dense soil structure *(Experiment 12)*, lower humus content *(Experiment 16)*, lower water-holding capacity *(Experiment 9)* and water permeability *(Experiment 10)*, less biological activity *(Experiment 18)* and, last but not least, an accumulation of pollutants.

17. Overfertilization of soil

The appearance of increased nitrate concentrations in ground water and in foods has been a subject of much attention in the discussion on environmental protection in recent years. Although no direct harm to humans by nitrate (primary effect) is known, secondary effects are possible from the conversion of nitrate to nitrite in the stomach and intestine. Tertiary effects resulting from the formation of nitroso compounds, which are in part carcinogenic, are also possible. A limiting value for nitrate of 50 mg/l water is expected to be fixed as a result of the adaptation of the 1976 German Drinking Water Regulations to the EC-Guidelines. The Dietary Regulations of 1982 lays down a limiting value for the nitrate content of 250 mg/kg fresh weight, e.g. for salad and carrots intended for babies and small children *(Experiment 17)*.

Evaluation

Classification of vegetables according to their average nitrate content (mg/kg fresh substance; see Fig. 21.1).

Fig. 21.1: Classification of sorts of vegetables according to their nitrate content

Nitrat content	High 1000-4000 mg/kg	Average 500-1000 mg/kg	low 0-500 mg/kg
Green vegetables	Lettuce, fennel chard, corn salad, spinach		
Cabbage vegetables	Curly kale, white cabbage savoy, chinese cabbage	Cauliflower Turnip cabbage	Brussel sprouts
Roots	Beetroot, radish, radishes	Celery, carrots	Potatoes
Bulbs		Leek	Garlic
Fruit vegetables		Egg-plant, zucchini	French beans cucumber, tomatoes, paprika

Nitrate content	in fresh substance	Sort
Very low	250 mg/kg	Beans, peas, tomatoes
low	500 mg/kg	Cauliflower, cucumber
Moderate	1000 mg/kg	Cabbage, carrots
high	2000 mg/kg	Leek, rhubarb
Very high	> 2000 mg/kg	Beetroot, lettuce, spinach

Measures

An important factor which influences the nitrate content of vegetables is the amount of available nitrogen, as with increasing nitrogen fertilization, the plant can take up and store more nitrate. This is equally true for organic manures and mineral fertilizers. A well calculated nitrogen fertilization is therefore necessary to reduce the nitrate content of vegetables, i.e.:

- Tailor-made fertilization acc. to the N min method,
- distribution of small amounts of fertilizer over the course of the vegetation period,
- slow acting organic fertilizer (e.g. compost),
- gearing of the fertilization to the other growth factors (water, light),
- cultivation of low-nitrate types of vegetables or removal of the nitrate-rich veins of leaves,
- checking the nitrate content with test strips.

Fig. 21.2: Regulation (E), limiting value (G) and guiding value (R) for nitrate

Nitrate intake by adults	WHO-E	220 mg NO_3^-
Drinking water	EC-G	50 mg NO_3^-/l
Drinking water	EC-R	25 mg NO_3^-/l
Dietary food	D-G	250 mg NO_3/kg
Spinach	D-R	2000 mg NO_3/kg
Corn salad	D-R	2500 mg NO_3/kg
Lettuce, radishes, beetroot, radish	D-R	3000 mg NO_3/kg

18. Soil acidification

The acidification of soil is, under European climatic conditions, a natural soil development process, as a result of the precipitation of naturally acidic rainwater. This process is, however, being considerably accelerated by man. To this extent, soil acidification belongs to the anthropenic environmental changes *(Experiment 14)*.

Evaluation of the soil pH

The evaluation of the pH must be made against the background of the particular soil buffer system. Soil has various buffer systems for the acid content, and they are each effective in different pH ranges:

Buffer range	pH
Calcium carbonate	6.2-8.3
Silicate	5.0-6.2
Exchanger	4.2-5.0
Aluminium	3.8-4.2
Aluminium/iron	3.2-3.8
Iron	2.8-3.2

The *chalk buffer* neutralizes acids by reaction with chalk (calcium carbonate); and so adjusts the pH to 8.3-6.2. In agriculture, this buffer is renewed by each liming. When the chalk is exhausted, or not present, as in the case of low-chalk soils, then the pH drops below 6.2. Acids are then neutralized by the *silicate buffer* down to a pH of 5.0. Hydrogen ions are taken up in the crystal lattice of the silica mineral and, in return, nutrients such as potassium are liberated. The conditions are favourable for plants and soil life in this buffer range. With the exceptions of chalk landscapes, the silica buffer range would predominate in Central European soils, when the natural soil chemistry equilibrium was not disturbed by the anthropogenic ingress of acid.

As a result of this load of acid, many soils are instead in the *exchanger buffer system* (pH 5.0-4.2), where hydrogen ions are bound to the soil exchangers (clay minerals and humic substances), so liberating nutrients (e.g. Ca, Mg) which are then washed out into deeper soil layers. For this reason, the result of soil acidification in this buffer range is not only acid damage, but also a deficiency in nutrients. Should this buffer system also be exhausted by a continuing input of acid, then, at a pH below 4.2, aluminium and iron ions are set free from the soil minerals. Most forest soils are already in the *aluminium buffer range* (pH 4.2-3.8). As the aluminium ions which are liberated are strongly cytotoxic, damage is caused to forests by such soils.

When the *buffering capacity* of soil, i.e. the quantity of hydrogen ions which can be neutralized by each particular buffer substance, is related to the amount of acid presently being brought into the soil, it can be seen that practically all chalk-free soils will acidify into the range of aluminium liberation. The result will be the loss of nutrients, damage to microorganisms and plant roots, and widespread damage to forests, as well as a threat posed to ground water by poisonous ions.

Room for notes

0. General description of the location

1. Soil profile
- Soil horizons
- Soil types

2. Mineral matter
- Stone content
- Fine earth contents
- Soil texture

3. Body of humus
- Humus content
- Kind of humus

4. Water/air
- Soil moisture
- Water capacity
- Water permeability
- Available water

5. Soil structure
- Soil compaction
- Aggregate stability/tilth

6. Acidity
- pH value
- Lime content

7. Nutrients
- Nitrate content of the soil
- Nitrate content of vegetables

8. Life in the soil
- Soil animals

9. Taking soil samples

Equipment and materials

Soil examination	Set for group (6 each)	Simple equipment	External equipment
General	• Dish • Trowel • Spoon • 2 Plastic bags with closures	• Balance • 500 ml water bottle • Measuring cylinder (100 ml) • Bottle of $CaCl_2$ (500 ml)	• 6 desk pads with pencil • Water tank • Waste bag
Soil profile – Soil horizons – Soil type		• Measuring tape (2 m)	• Pürkhauer (auger), Plastic hammer, Folging spade, Knife
Mineral matter – Stone content – Fine earth component – Soil texture	• — dish, wire netting • —	• Balance • Water	
Body of humus – Humus content – Kind of humus	• — Funnel, filter Snap cover bottle Beaker (250 ml)	• 3 Dropping bottles /ammonia (2%ig)	
Water/air – Soil moisture – Water capacity – Water permeability	• — • Beaker, funnel, filter • Beaker, funnel, filter	• — • Measuring cylinder	• Metal can, clock • Hammer, board
Soil structure – Soil compaction – Type of structure/ stability	• Petri dish	• 1 Soil compaction probe, • 1 Dynamometer • Water bottle	
Acidity – pH value – Lime content	• pH Test sticks with colour code, filter, beaker (250 ml),spoon • Petri dish	• Balance, $CaCl_2$ • 3 Droppingbottles/HCl,	
Soil nutrients – Nitrate	• Nitrate test sticks with colour code, beaker, filter, spoon	• Balance	
Life in the soil – Soil animals	• Catchment exhauster, Brush, snap cover bottle, lens, dish	• Storage vessel for soil fauna	

Soil protocoll

Date:	Location:	Relief:
Name:		Inclination:
		Vegetation:

cm	Sketch of profile	Horizon
20		
10		
10		
20		
30		
40		
50		
60		
70		
80		
90		
100		

Soil type: ....

Stone content/ fine earth: ....

Soil texture: ....

Humus content: ....

Kind of humus: ....

Water capacity: ....

Water permeability: ....

Soil compaction: ....

Aggregate stability: ....

pH value: ....

Lime content: ....

Nitrate content: ....

Plants
•
•
•
•
•
•
•
•
•

Soil animals
•
•
•
•
•
•
•
•
•

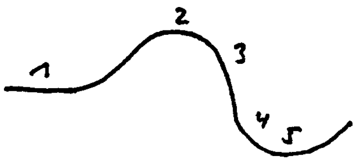
General description of the location

Before starting to examine the soil, note the most important data such as location, vegetation, relief and inclination.

Vegetation: Differentiate between the following forms of vegetation, or its utilization:

Arable land, pasture land, special cultivation (e.g. a garden), fallow, other usage (e.g. park, green space), wood, forest, wasteland:

Relief:



1. Plain
2. Hill-top
3. Convex slope
4. Concave slope
5. Gully and hollow

The relief effects the available water in the soil and so the supply of air.

Available water (2 < 3 = 1 < 4 < 5).

Inclination:

Estimation of the inclination:
Flat, slightly inclined, moderately inclined, strongly inclined, steep

Assessment: A strong inclination of a sunny slope increases the soil temperature; with strongly inclined shady slopes the opposite is the case.

Exeriment 1: Identification of the soil horizons

Method: Each soil is divided into various horizons, which can be easily recognized by their different colours, humus/mineral content and other characteristics.

Material: (possibly soil auger, hammer spade), trowel, measuring tape

Procedure: The soil horizons can be observed at the edge of a fault in the earth, in vertically excavated soil (using a spade or trowel) or in a core of soil (using a Purkhauer). Check which of the horizons described below are present and sketch them in the worksheet.

O **Organic deposits on the top of mineral soils (except for peat)**

— Formed from accumulations of organic material (litter, plant residues)

— Organic material is generally poorly decomposed

A **Upper mineral soil horizon**

— Humous, dark coloured horizon

— Humified organic matter is intimately associated with the mineral fraction

— Organic matter is well decomposed

— Horizon is darker than the underlying horizon

B **Brunified horizon below the A-horizon**

— Brunified by mineral weathering, lighter than the A-horizon

— Rock structure is obliterated

— Illuvial concentration of clay, iron or organic matter is possible

C **Parent rock of soil formation (bedrock)**

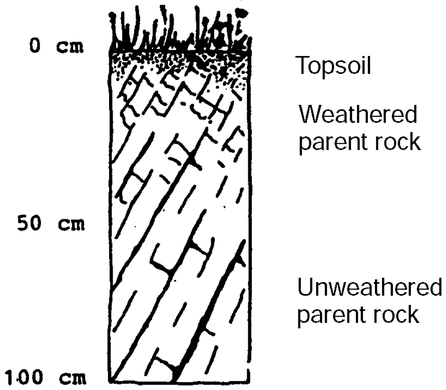
— Weakly weathered, lossened

— Unweathered

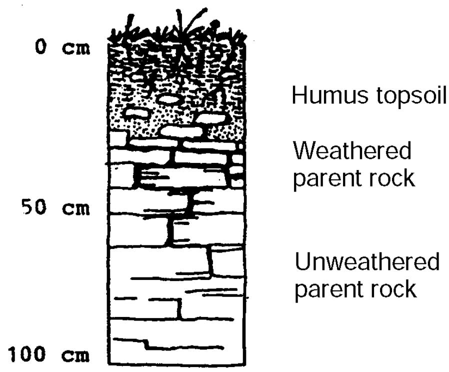
Experiment 2: Determination of the soil type

Method: The soil type can be determined from the characteristic combination and succession of certain soil horizons.
Procedure: Compare the horizons of the soil (see "Identification of the soil horizons") with the diagrams below. Determine the soil type.

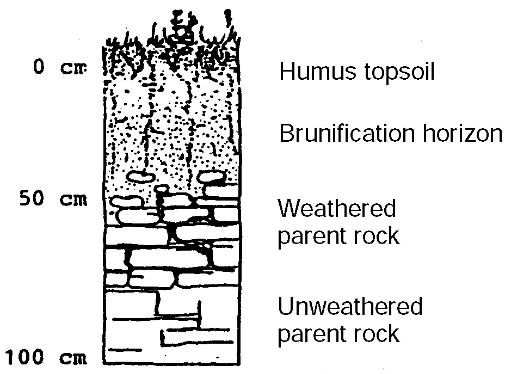
Evaluation (diagram):



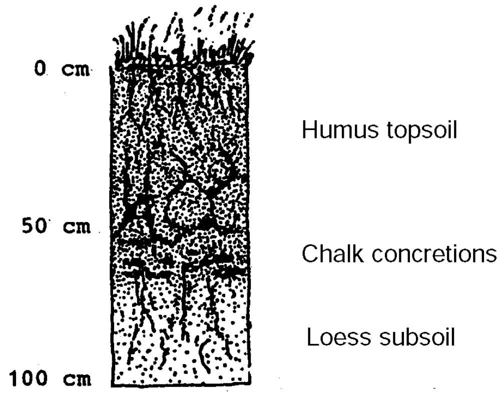
Lithic Leptosol ***(A-C)***



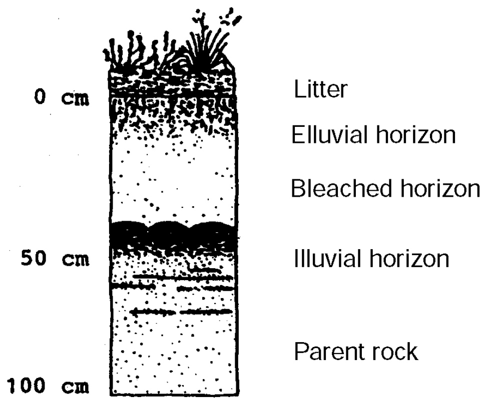
Leptosol ***(A-C)***



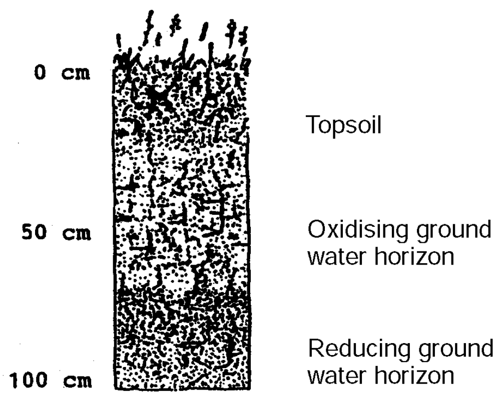
Cambisol ***(A-B-C)***



Chernozem ***(A-C)***



Podzol ***(O-A-B-C)***



Gleysol ***(A-B)***

Experiment 3: Estimation of the stone content

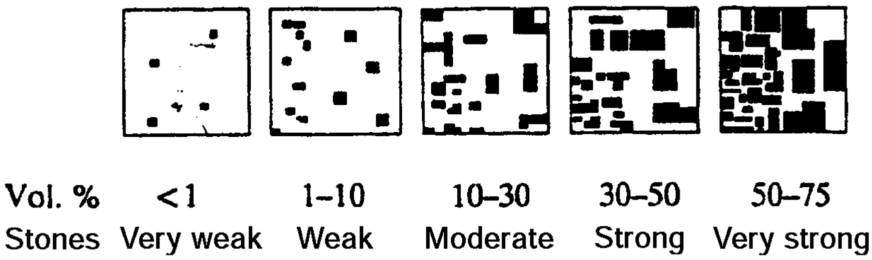
Method: The stone content of the soil can be estimated using a surface evaluation scale.

Material: Trowel

Procedure: Excavate a little soil so that a vertical cross-section is visible (similar to Experiments 1 and 2)

Estimate the stone content from their volume share as to be seen in the profile of the soil.

Evaluation:



Vol. % of stones	< 1	1 - 10	10 - 30	30 - 50	50 - 75	> 75
Stoniness	Very weak	Weak	Moderate	Strong	Very strong	Skeletal soil

Assessment: The volume requirements of a high stone content reduces the content of fine soil, which is of importance for the fertility of the soil.

Experiment 4: Determination of the fine earth content

Method:
The fine earth content (diameter < 2 mm) is of first and foremost importance for the quality of a soil. It will be used in all of the experiments which follow

Material:
Granulating sieve, balance

Procedure:
Put one or two shovelfuls of soil on the 2 mm sieve and sieve fine earth into the dish. Weigh both fractions (coarse soil/fine soil) and calculate the percentage of the coarse soil.

The fine soil is needed for further examinations of the soil.

Experiment 5: Determination of the soil texture

Method:
The granulation of the fine soil (particles < 2 mm), i.e. the soil texture, is determined in the field by the finger test. The criteria which serve mostly to differentiate the soil textures are the plasticity of form, graininess, cohesion and brilliance of a rubbed surface.

Material: Water, soil auger or trowel
Procedure: Take a little soil from the mineral soil horizon (depth approx. > 30 cm), wet it slightly in the palm of your hand and knead it until the brilliance from the moisture disappears. In this way, a "standard" soil moisture is attained. Subsequent to this, proceed with the identification key, with which the following criteria can be determined (see Experiment 5, page 2).

1. Plasticity of form: Test if the soil can be formed to a stable body by kneading it (e.g. to a sausage as thick as a pencil).

2. Graininess: The grain content which can be identified as individual grains on rubbing the soil between your fingers.

3. Cohesion/stickiness: The resistance which a piece of soil pressed between your fingers exerts when you take your fingers apart.

4. Brilliance of a rubbed surface: Stroke a small amount of soil between your fingers so that it is smooth. Observe the smooth surface against the light to determine if it gleams.

Sources of error: The determination of the soil texture is difficult when there is a high content of organic matter, as this increases the cohesion and plasticity of form. Because of this, move in particular all sands back 1-2 granulation classes, according to their humus content.

Experiment 5: Determination of the soil texture by finger testing (page 2: Key)

Diagnostic feature	Soil texture
1. Try to quickly roll the sample to a pencil-thick sausage between your finger.	
a. Cannot be rolled: Sand group	continue at 2
b. Can be rolled: Sandy loam, loam and clay group	continue at 4
2. Test the cohesion between thumb and forefinger	
a. Not cohesive: Sand	continue at 3
b. Cohesive:	Loamy sand (IS)
3. Rub it firmly between your hands	
a. No clayey material to be seen in the lines of the hands:	Sand (S)
b. Clayey material to be seen in the lines of the hands	Sandy loam (Sl)
4. Try to roll the sample to a sausage half as thick as a pencil	
a. Cannot be rolled:	Very sandy loam (SL)
b. Can be rolled: Sandy loam, loam or clay	continue at 5
5. Sqeeze the sample between thumb and forefinger next to your ear	
a. Strong crunching:	Sandy loam (sL)
b. No, or only weak, crunching: loam or clay	continue at 6
6. Judge the flat surface from the squeezing test	
a. Dull surface:	Loam (L)
b. Gleaming surface: Clay	continue at 7
7. Test the sample between your teeth	
a. Crunching:	Loamy clay (LT)
b. Butter-like consistency:	Clay (T)

Experiment 6: Estimation of the humus content

Method: The humus content can be estimated from the gray component of the colour of the moistened soil.

Material: Sheet of white paper, water, trowel

Procedure: Slightly moisten a shovelful of soil (from the A-horizon) and lay it on the sheet of paper. Estimate the gray component of the colour of the soil using the Table given below. A comparison between two soils is easier than an absolute determination.

Evaluation:

Sand is darker than finely granulated earth of the same humus content.

colour	Humus content in %	
	Sand	Loam/Silt/Clay
white		< 0.2
light gray	< 0.2	0.2 - 1
gray	0.2 - 1	1 - 2
dark gray	1 - 2	2 - 4
blackish-gray	2 - 4	4 - 8
black	4 - 15	8 - 15

Humus content	0 - 0,2	0,2 - 1	1 - 2	2 - 4	4 - 8	8 - 15	15 - 30	> 30
Description	Very humus-poor	Humus poor	Humic	Humos	Humus-rich	Very humus-rich	Moorish	Peat

Assessment:

Humus promotes the
- Water-holding capacity and the water permeability
- Warming of the soil
- Loose soil structure
- Supply and storage of nutrients

Experiment 7: Analysis of the form of humus

Method: The form of humus can be determined by means of an extract of the soil with ammonia solution.

Materials: Funnel, filter, glass beaker, snap-cover bottle

Procedure:
— Extract approx. 5 g of soil (a spoonful) with approx. 10 ml ammonia solution in a snap-cover bottle!
— Filter the solution into the beaker!

Determine the form of humus on the basis of the colour of the filtrate

Evaluation:

Colour of the filtrate	Form of humus
As light as water	Mull
yellow (bright)	Mixture of mull and raw humus (moder) – Low raw humus share
yellow (dark)	– High raw humus share
Dark brown	Raw humus

Assessment:

Criterium	**Mull**	**Moder**	**Raw humus**
Decomposition of litter	++	+	(–)
Burrowing animals	++	+	–
pH	neutral to weakly acidic	acidic	strongly acidic
Nutrient supply	good	moderate	bad

++ = very distinct   + = distinct   (–) = hardly recognizable   – = missing

Experiment 8: Estimation of soil moisture

Method: The estimation of the moistness of the soil allows the actual degree of saturation with water to be ascertained.

Materials: Trowel, water

Procedure: Take a little soil in your hand and examine its behaviour when you press, shape, wet and rub it (see the Table below).

Evaluation:

Pressing on the sample	**Forming (to a ball)**	**Wetting the sample**	**rubbing (in a warm hand)**	**Moistness**
Raises dust	does not cohere	darkens strongly	not lighter	arid
Raises dust	does not cohere	darkens noticeably	hardly lighter	dry
Raises dust	formable (except for sand)	does not darken	noticable lighter	fresh
Sticks	a little free water or weak gleaming	does not darken	noticable lighter	moist
Free water	runs or water drops of	does not darken	noticable lighter	wet
Free water	falls apart	does not darken	noticable lighter	very wet

Experiment 9/10: Examination of the water capacity and the water permeation rate

Method: The water capacity can be found by saturating a soil with water and determining the amount of water held by the soil. The water permeation rate is given by the quantity of water which passes through it per unit time.

Equipment/Materials: Beaker, funnel, measuring cylinder, water, balance.

Transfer approx. 30 g of soil, dry if possible, onto a filter in the funnel.

Pour 30 ml of water onto the soil sample and catch the water which flows through in the beaker.
When the water has flowed through, pour the water collected in the beaker back on the soil. Repeat this process several times, until the soil is saturated with water.

During the second or third passage of water, determine the flow rate by counting the drops per minute, or 4 x 15 seconds (= dropping rate).

Evaluation: When the water has passed completely through, the amount of water which the soil has taken up is found from the water remaining.

Water capacity (% by weight) = Quantity of water taken up .... (ml) x 100

Weight of the soil .... (g)

The **water permeation rate** is given directly by the drops per minute.

Experiment 11: Examination of the available water capacity

Method: The available water capacity (awc) is understood as the binding capacity of the soil for plant available water. It correlates with the soil texture, humus content and bulk density.

Procedure: Calculate the available water capacity from the soil texture and humus content data.

Evaluation:

Soil texture	S	Sl	lS	SL	sL	L	LT	T
Vol. % awc	8	11	14	18	20	20	17	13

Increase the values according to the humus content in the following steps (by %):

	Humus-poor	Humus-containing	Humic	Humus-rich	Very humus-rich	Moorish	Peaty
for S- SL by	1	2	3	7	14	30	40 Vol. %
for sL- T by	0	1	2	4	8	30	40 Vol. %

Now reduce the available water capacity by the stone content (Experiment 3), e.g. when the stone content is 50% by volume, halve the available water capacity.

To obtain the available water capacity in l/m (or mm), multiply the available water capacity which has been corrected for stone content by the depth of the corresponding horizon (Experiment 1).

To obtain the available water capacity for the whole rooting space, add the appropriate (root penetrated) horizons together.

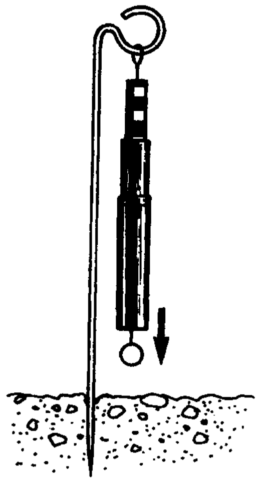
Assessment:

<	50	–	90	–	140	–	200	>	mm
Very low		low		moderate		high		very high	

Experiment 12: Measurement of soil compaction

Method: The degree of soil compaction can be determined from the resistance to penetration of a sharp object (soil compaction probe). This measurement only supplies comparative values.

Material: Spring balance, soil compaction probe



Procedure: Fasten the soil compaction probe to the spring balance. Pull on the spring balance to force the probe into the soil. While doing this, read off which force is required. Carry out several measurements at different positions and take the average of them.

Assessment: Compaction of soil has a negative effect on the water and air balance, and so on all biological processes in the soil.

Experiment 13: Measurement of the aggregate stability/tilth

Method: Tilth is an expression for a fertile soil with good physical, chemical and biological properties. It can be roughly estimated from the stability of the soil crumbs.

Materials: Water, Petri dish

Procedure:
Take a spoonful of soil from a depth of approx. 10-20 cm in its natural state, i.e. without changing its structure (e.g. without dividing it or pressing on it). Extract 20 crumbs, each roughly two to five millimeter large, from the soil, place them in the Petri dish and carefully cover them with water. Now bring the water to a circular movement for 30 seconds by carefully swirling the dish, in a similar way to how you dissolve sediment in a bucket or cup.

Estimate the resistance with which the soil particles oppose sludging from the way the water movement affects them.

Evaluation:

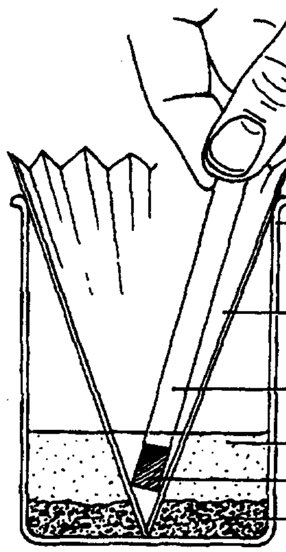
State of the aggregates after the test	Aggregate stability
No disintegration, or only large fragments	very high (100%)
Predominately large fragments	high (100%)
Large and small fragments about equal	moderate (50%)
Only small fragments and turbidity	low (15%)
Complete disintegration and very turbid	very low (10%)

Assessment: A high aggregate stability exerts a positive effect on the water and air balance and acts against soil erosion.

Experiment 14: Measurement of soil reaction (pH)

Method: The acidic condition of the soil is expressed by a pH value, which is a measure of the content of hydrogen ions in a liquid.

Equipment/materials: pH test strips, beaker, filter, $CaCl_2$-solution (0.1 M)



The pH of the water to be used can be previously measured as a control.

Procedure: Use fine soil as sample material. Prepare a sludge by mixing soil and $CaCl_2$-solution in a ratio of 10 g to 25 ml (e.g. 20 g soil, 50 ml $CaCl_2$-solution), stirring the mixture vigorously several times, and then allowing it to stand for a short time. It takes at least 10 minutes for an equilibrium to be attained in the sludge liquid. Now immerse a filter in the soil suspension, so that clear liquid collects inside the filter. Measure the pH of this clear liquid.

Keep the test stick immersed for about 3 minutes

Evaluation:

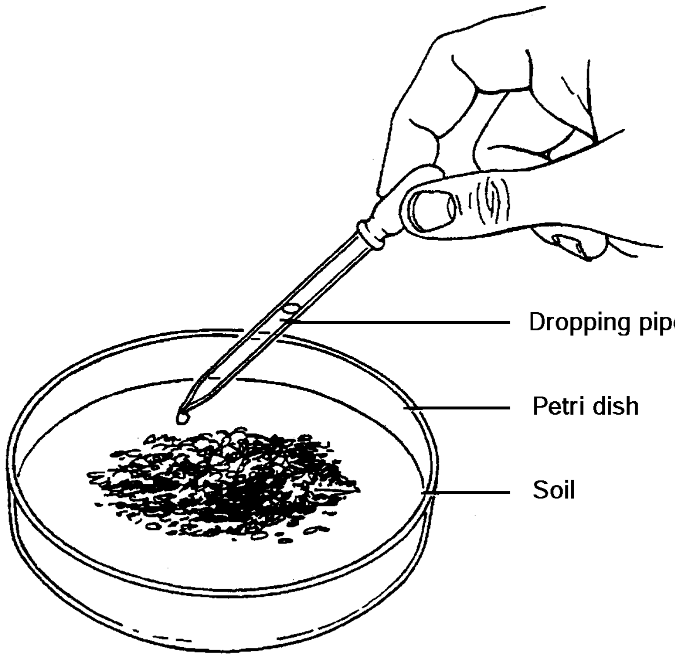
pH < 3.5	-4.5	-5.5	-6.5	-7.2	-8.5	>8.5
Extremely acidic	strongly acidic	acidic	weakly acidic	neutral	alkaline	strongly alkaline

Assessment: A neutral to slightly acidic pH of the soil (pH 6 to 7)
— promotes biological activity in the soil and so the humus conversion,
— increases the solubility of nutrients,
— prevents the liberation of poisonous aluminium ions,
— and promotes plant growth.

Experiment 15: Determination of the lime content

Method: Treat soil from the particular horizon with HCl and observe a possible development of CO_2 by means of a stronger or weaker formation bubbling. Hydrochloric acid is a strong acid and so displaces the weaker carbonic acid from its salts. Carbonic acid decomposes to water and carbon dioxide, which is evolved as a gas.

Equipment: Petri dish, dropping bottle with 10% hydrochloric acid



Procedure: Transfer a small quantity of soil to the dish. Add a few ml of dilute hydrochloric acid to it dropwise and observe any formation of bubbles.

Evaluation:

Reaction	Lime content	Judgement
No effervescence	below 1%	lime-deficient
Weak, brief effervescence	1-3%	weakly limy
Clear, transient effervescence	3-5%	limy
Strong, lasting effervescence	over 5%	very limy

Assessment: Lime regulates the soil pH.
Lime improves the soil structure.
Lime promotes life in the soil.

Experiment 16: Measurement of the nitrate content of soil (procedure)

Method: The nitrate content of the soil can be simply determined using nitrate test sticks. These have a colour indicator, which is coloured according to the amount of nitrate present.

Equipment/materials: Soil auger, spade or trowel, beaker, filter, nitrate test sticks, water, clock, balance

Taking the soil samples: According to the plant species, rooting reaches to different soil depths. The soil samples must therefore be correspondingly taken (down to 90 cm depth, e.g. with a soil auger).

Procedure: For each soil layer, weigh out 100 g of soil sample and stir it vigorously in 100 ml of water.

Dip a pleated filter in the soil suspension. Briefly (1 to 2 seconds) dip a nitrate test stick into the filtrate inside the filter. Should the soil suspension not filter easily, press the test stick briefly against the moist inside of the filter.

After waiting about 1 minute, compare the colour of the test stick with the colour scale on the container. The following Table gives a rough orientation on the supply status of the soil in dependence on the nitrate concentration. A more exact evaluation can be made on the basis of the individual N requirements of plants. The mg NO_3/l values given on the scale correspond in this experiment to kg N per hectare in the particular soil layer of 30 cm thickness.

Evaluation: When all three layers are added together, the kg value per hectare of the total soil from 0 to 90 cm is given. This is a rough value for the N min reserves in the soil.

Conc. nitrate (mg/l)	Supply status of the soil
0 - 40	low
40 - 75	average
75 - 150	high
150 and higher	excessive

Experiment 17: Measurement of the nitrate content of fruit and vegetables

Method: The nitrate content of food and drinks can be simply measured using test sticks (colour reaction).

Material: Nitrate test sticks

Procedure: Cut the plant through with a knife, wet a test strip at the cut surface (1 sec). Wait one minute, then compare the test stick colour with the colour scale.
Plant material can also be crushed with a household press (e.g. a garlic press) to win plant juice. With plant material which has a high nitrate content, the pressed out juice is multiplied by the appropriate dilution factor (10 here).

Evaluation: The reading is in mg nitrate per kg of plant material.

Assessment: High nitrate contents in foods impair health!

Nitrate intake by adults	WHO-E	220 mg NO_3^-
Drinking water	EC-G	50 mg NO_3^-/l
Drinking water	EC-R	25 mg NO_3^-/l
Dietary food	D-G	250 mg NO_3^-/kg
Spinach	D-R	2000 mg NO_3^-/kg
Corn salad	D-R	2500 mg NO_3^-/kg
Lettuce, radishes, beetroot, radish	D-R	3000 mg NO_3^-/kg

Regulation (E), limiting value (G) and guiding value (R) for nitrate.

Experiment 18: Identification of soil animals

Method: "Larger" soil animals can be collected from the leaf litter or from the upper soil layer.

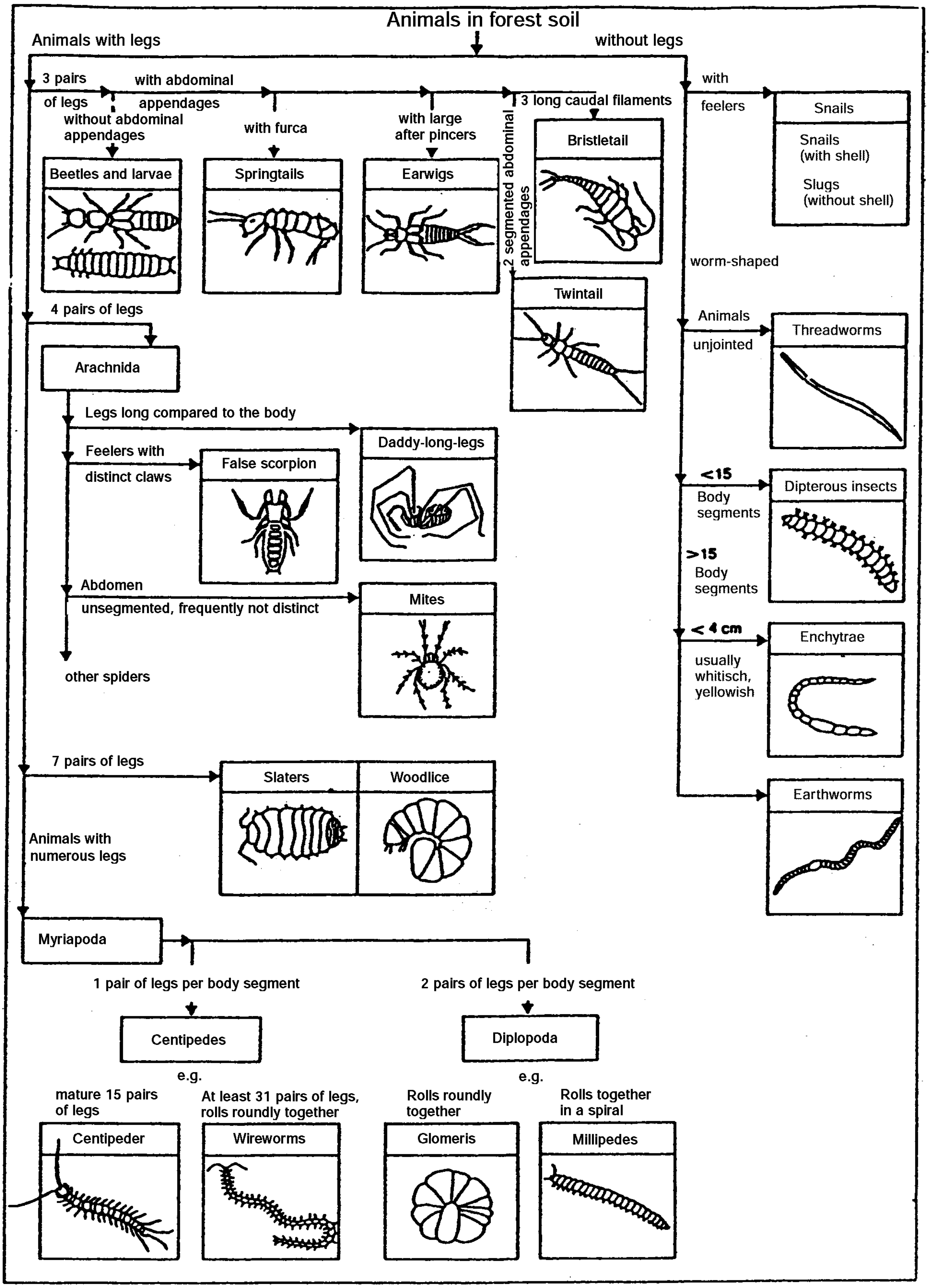
Materials: Catchment exhauster, brush, snap-cover bottle, magnifying glass, dish

Procedure:
1. You can pick up smaller animals with the brush and put them in a Petri dish (with lid).
2. Suck up the smallest animals with the exhauster and put them also into a Petri dish.
3. Sieve the leaf litter and look through the sieved fine material for smallest animals.
4. Use the identification key (next page) to arrange the animals found in the following groups and enter the number of each in the Table or in your soil protocol.

Evaluation:

Group	Number	Group	Number
1. Springtails		10. Mites	
2. Ants		11. False scorpions	
3. Total beetles		12. Myriapoda, total	
a) Ground beetles		a) Millipedes	
b) Click beetles		b) Glomeris	
c) Brachypterous		c) Wireworms	
d) Weevils		d) Centipedes	
4. Snails		Other species:	
5. Slaters/woodlice		13.	
6. Earthworms		14.	
7. Spiders		15.	
8. Daddy-long-legs		16.	

Experiment 18: Identification key for soil animals

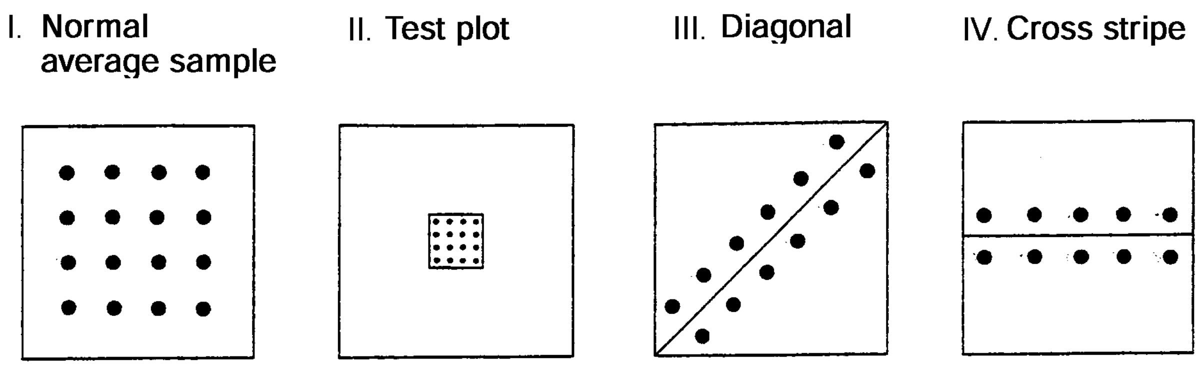


Experiment 19: Taking soil samples

Soil samples can be taken from the location, so that they can be examined more closely in the (school) laboratory.

Materials: Trowel, plastic bags, pencil

Procedure: In order to eliminate chance, which could mean that a sample taken at one point only is not representative, a so-called mixed sample should be taken, i.e. you should take separate soil samples at various points and mix them. The number of separate samples to be taken is dependent upon the size of the area under examination.
For an area of 100 m^2, take 10 separate samples for the mixed sample, and for an area of 20 m^2, take 5 separate samples for the mixed sample.



According to the soil factor which is to be examined, samples are taken from the topsoil or the subsoil.

Topsoil (down to approx. 30 cm)	— Humus content — Life in the soil — pH, lime content
Subsoil (approx. 30-60 cm)	— Soil texture — (pH, lime content)
Topsoil and subsoil, always separate	— Nitrogen

The separate samples of the topsoil and of the subsoil should be collected in two separate buckets and each must be thoroughly mixed. To obtain samples which are as typical as possible, it is recommended that you discard the transition range between two horizons, and only take soil from the main body of the characteristic horizon. All peculiarities, such as particular discolourations etc., should be treated separately. Subsequently, sieve the samples to separate coarse ingredients, such as stones and roots.

29. Contents of the Soil Kit 30836.88

Description	*Order no.*	*No.*
Dish, plastic, 150x150x65 mm	33928.00	6
Brush, fine	64702.00	6
Magnifying glass, large	64600.00	6
Snap-cap vials, 85 ml, 10 pcs	33623.03	1
Rubber stopper, *d* = 27/21 mm, 2 holes 7 mm	39257.02	6
Glass tubes, straight, 80 mm, 10 pcs	36701.65	1
PVC tubing, *i.d.* = 7 mm, 1 m	03985.00	6
Wire gauze square, 150x150 mm	33284.00	6
Petri dishes, plas., *d* = 94 mm, 20 pcs	64709.03	1
Soil density probe, NIRO, *l* = 58 cm	64244.00	1
Scoop, steel	40484.02	6
Beaker, 250 ml, low form, plastic	36013.01	6
Funnel, PP, *d* = 75 mm	46895.00	6
Dropping bottle, plastic, 50 ml	33920.00	6
Measuring scoop, 10 ml	47457.00	6
Bag with closure, PE, DIN A5, 100 pcs	46444.01	1
Square flask, PE, narrow neck, 500 ml	47396.00	1
Square flask, PE, wide neck, 500 ml	47400.00	1
Graduated cylinder. 100 ml, plastic	36629.01	1
Measuring tape, 2 m	09936.00	1
Round filter, qual., *d* = 150 mm, 100 pcs	47570.06	1
Spring balance, transparent, 100 N	03065.07	1
Balance, 250 g	46000.00	1
Merckoquant nitrate-test, 100 pcs	31679.10	1
Spec. indic. rods, pH 2.0-9.0, 100 pcs	30301.06	1
Handbook Examination of soil	30836.02	1

The following are additionally required or recommended:

Environmental Atlas Soil, software	83017.00	1
Ammonia solution, 25%, 250 ml	30933.25	1
Calcium chloride hexahydrate, 100 g	48020.10	1
Hydrochloric acid, 10%, 500 ml	31821.50	1
Soil auger, *d* = 3 cm, *l* = 1 m	64221.01	1
or:		
Soil auger, small, *d* = 13 mm, *l* = 48 cm	64222.00	1

30. The use of a computer in soil science examinations

The examination of soil in the field using the "Phywe Soil Kit" can be supported by software for data evaluation. The educational software "Environmental Atlas Soil", from the "Institute for Film in Science and Education", is particularly suitable for this purpose, as it is closely matched to the experiments which can be carried out with the Soil Kit.
The "Environmental Atlas Soil" supports the collection of data with texts on the most important soil factors, which can be called-up as required, as well as with geographical, soil science and geological maps.
The data obtained from the examination of the soil can be entered in a worksheet, saved and compared. This is of particular interest for comparisons of:

- Soils of different ecosystems (forest against meadow, or town)
- Soils with different vegetation (deciduous forest against coniferous forest)
- Soils along a transekt (forest, forest edge, pasture, field)
- Soil being managed in different ways (conventional against ecological)
- Soils in different locations (transekt along a relief) having different soil types
- Soil factors over several years (e.g. a check on fertilization measures).

In addition to this, field testing with the Phywe Soil Kit can be expanded by (school) laboratory examinations of the soil (Environmental Atlas Soil). The calculation of the lime and nitrogen fertilization required, as well as the simulation of soil processes, are further helpful supplements.

31. Literature

FAO (1988):
FAO/UNESCO Soil Map of the world, Revised legend, with corrections and updates.

World Soil Resources Report 60, FAO, Rome
Reprinted with updates as: Technical Paper, 20, JSRIC, Wageningen, Netherlands, 1997.