Project: Partnership for the development of training standards for tree assessors in Central and Eastern Europe

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TREE
ASSESSOR

Soil assessment

Advanced tree assessment –
manual for professionals

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Soil assessment

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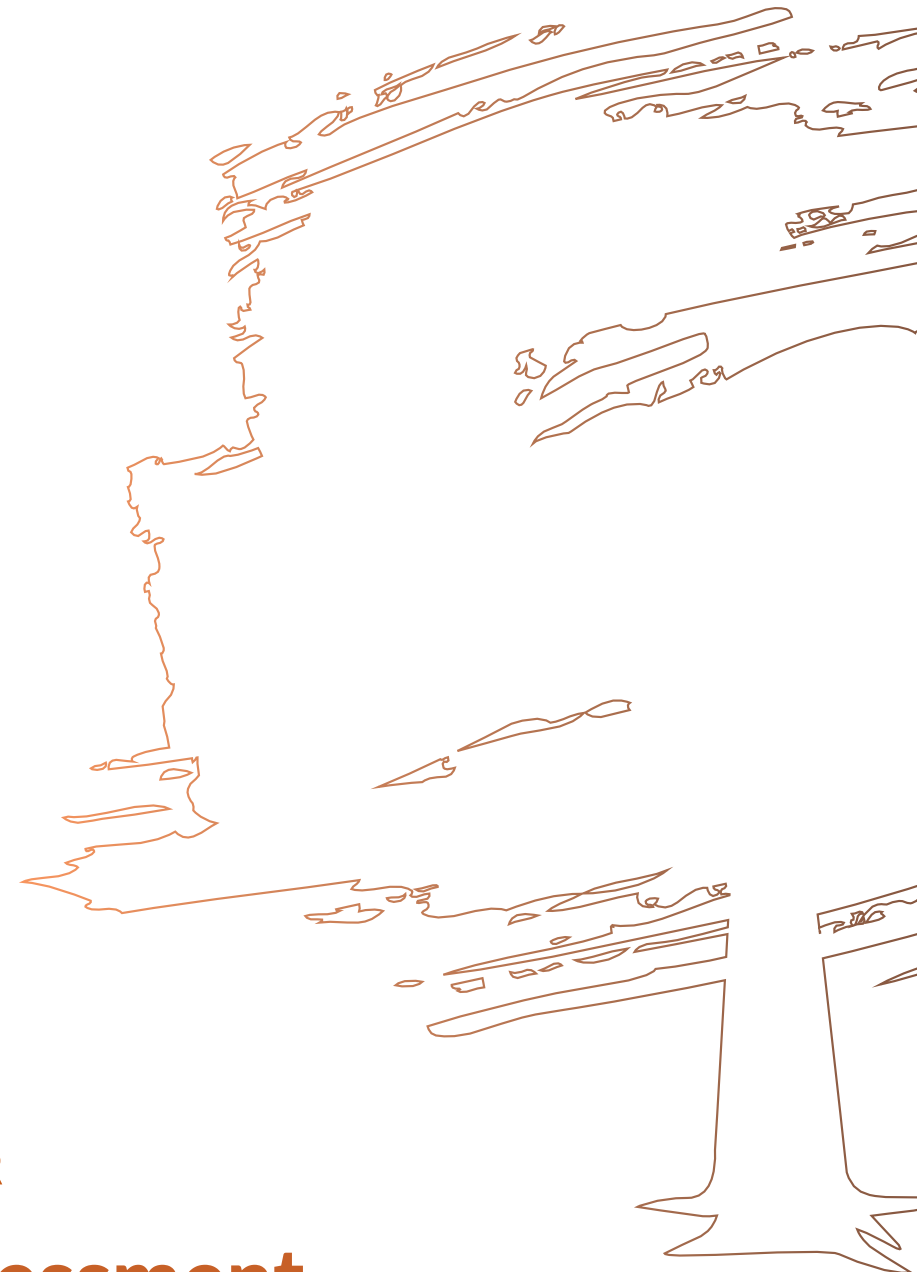

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Introduction

Soil is crucial for the growth and development of trees - trees are rooted in the soil and it also serves as a source of water and minerals. Soil is a complex system of organic and inorganic substances, water and air. Soil is home to countless organisms - bacteria, algae, fungi, worms, insects, and a variety of larger animals, such as moles. Soil has an important role in the whole biosphere of the Earth - it participates in the cycles of water, oxygen, nitrogen, carbon. Under natural conditions, the soil composition and properties depend on climate, geographic location, topography and the historic management of the particular site. In urban areas, however, the natural soil is often partially or completely degraded by human actions. The economic activity has affected the soil, polluting and subjecting it to erosion.

Soil assessment is necessary to understand the properties and the potential problems of the soil, and such can be done by probing, collecting and analyzing soil samples.

Unsuitable soil conditions for trees can be reversed by improving the soil, changing its structure, draining or providing moisture, as well as by agrotechnical treatments and additional fertilization. Knowing the soil conditions necessary for the particular trees we can choose appropriate soil management measures to ensure tree vitality and longevity.

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I.

Soil characteristics

1. DEFINITION AND IMPORTANCE OF SOIL

Soil is a loose top layer of the lithosphere, formed by a mixture of organic matter, minerals, water and gaseous substances. Soil is an important part of Earth's biosphere, which is in close interaction with lithosphere, atmosphere and hydrosphere through the life cycles of various substances such as oxygen, carbon and nitrogen, as well as water. The soil layer is called pedosphere (from the Greek pedon – land, soil) (Figure 1).

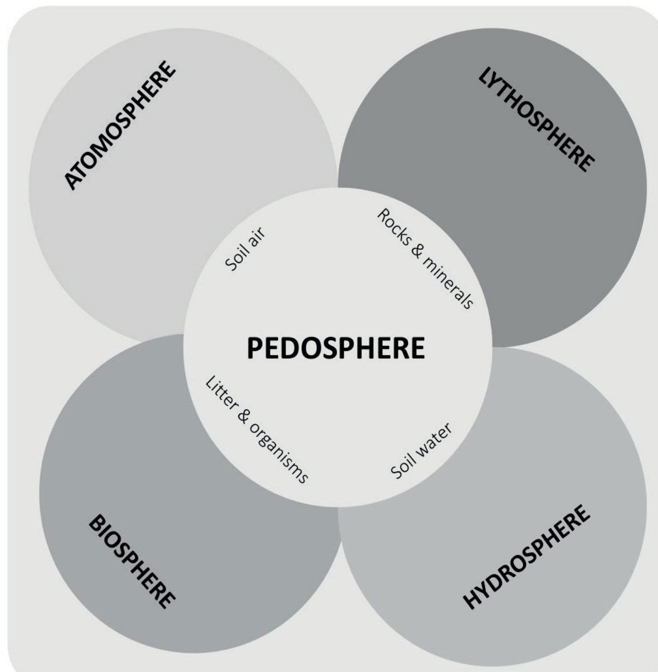

Figure 1. Relation of soil or pedosphere to other Earth's shells. (J.Gerrard (2000)

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Most soils on Earth were formed during the Pleistocene, i.e.2.5 million– 11.7 thousand years ago. Soil is formed by the action of climate and living organisms on the bedrock. Soil formation is determined by geographical location and site-specific minerals, micro-organisms, humidity conditions and various environmental processes such as erosion. An important indicator is the fertility of soil, which is determined by the amount of organic matter in the composition of the soil. Soil that is suitable for plant growth consists of ~50% of solid particles (minerals and organic matter), 25% air and 25% water (Figure 2). The mutual ratio between soil components may vary depending on the specific type of soil, as well as the type of land use and treatment. Transformation of the mineral part of soil is the slowest, while changes in the organic areas of soil, the amount of water and air, as well as the chemical composition and processes can occur very rapidly.

Soil has several important functions:
- ensure the growth of plants, including woody plants;
- ensure water circulation, purification and storage;
- provide habitat for soil organisms (bacteria, protozoa, fungi, various invertebrates, etc.)
- direct impact on processes in the Earth's atmosphere;
- importance for the production of agricultural products;
- participation in the circulation of substances (carbon, oxygen, water life cycle);
- soil has cultural and historical value.

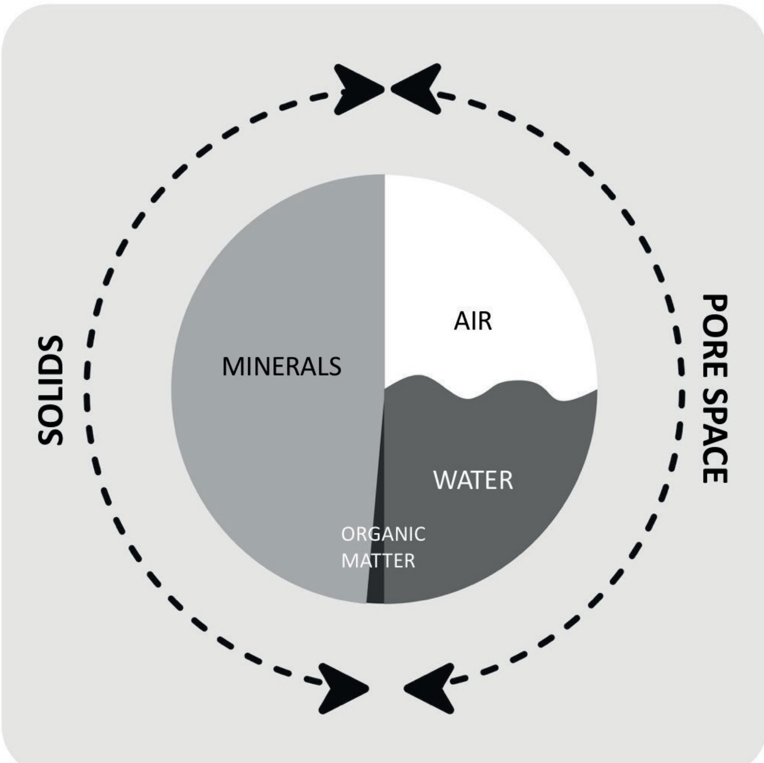

Figure 2. Soil composition suitable for plant development.

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Soil is considered to be an important and renewable natural resource. Soil fertility may determine the market value of land and it is often used to calculate the assessed value of the property. Information on soil characteristics and fertility is crucial for agronomists, foresters, spatial planners, as well as landscape architects and gardeners when planning and planting the greenery.

2. PHYSICAL PROPERTIES OF SOIL

2.1. SOIL DENSITY AND BULK DENSITY

Soil has physical properties. There are pores of different types and sizes, as well as different solid particles capable of forming aggregates of different sizes. It is determined by the mineral composition of the soil, the amount of organic matter in the soil, the chemical properties of the soil and other factors. The density of soil is characterized by soil particle density and bulk density.

Soil particle density is the average mass of soil particles per volume unit expressed in grams per cm-3. This density is determined mainly by the mineral and granulometric composition of the soil. The average soil particle density of mineral soil is 2.65 g cm^{-3}.

Soil bulk density is the absolutely dry mass of the soil per volume unit. It is expressed in g cm^{-3} or t m^{-3}. This volume includes both the solid particles and the air space of the soil. Bulk density describes the total porosity of the soil, for example, a small density (below 1.3 t m^{-3}) refers to a porous soil that will have better draining properties and will be more

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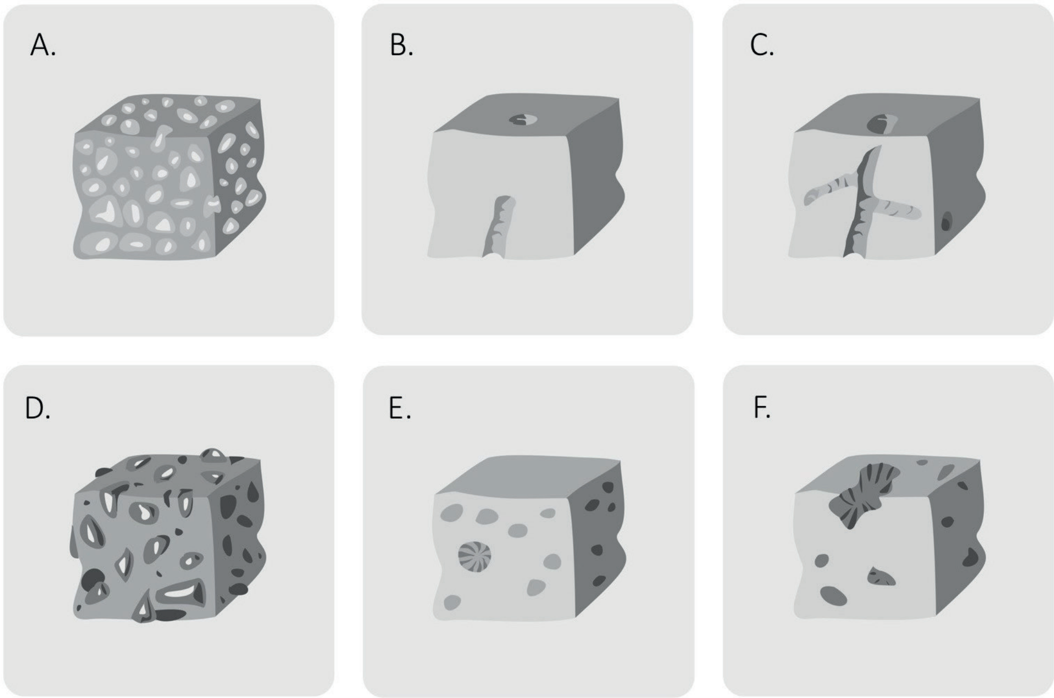

Figure 3. Types of soil pores or voids: A: texture pores (sandy particles), B: soil cavities, C: tunnels, D. texture pores (fragments of different soil particles), E. bubbles, F. irregular pores.

suitable for plant development. The bulk density of soil is an important indicator of soil quality.

2.2. SOIL POROSITY

Soil aeration, air and water regime, temperature and microorganism activity are affected by voids between soil aggregates and solid particles, i.e. soil porosity. Soil pores or voids are formed when soil particles do not come into contact with each other and do not fit densely on each other, as well as during root growth, under the influence of animal activity, or leaching. Soil voids or pores can be diverse. The porosity of the soil is expressed as cm^3, cm^{-3} or as percentage. The types of soil pores are subdivided (Figure 3):

- soil texture pores are formed in relation to the texture of the soil (how close particles fit to each other);
- bubbles are enclosed spherical or elliptical pores, formed during the process of soil compaction when the soil air is blocked;
- soil cavities occur as a result of the activity of animals within the soil;
- tunnels are extended, stretched pores or voids of soil resulting from the action of animals or root growth;
- cracks are formed when soil freezes and thaws, gets soaked and dries out, as well as during compaction. Soil cracks have various types: crust cracks, cracks passing through horizons, seasonal cracks, short-term cracks, permanent cracks (Figure 4).

Soil porosity is influenced by soil origin and type:

- soil porosity in gravel is 35%;
- sand sediments 39% -42%;
- loamy sand 45%
- loam 47% -50%

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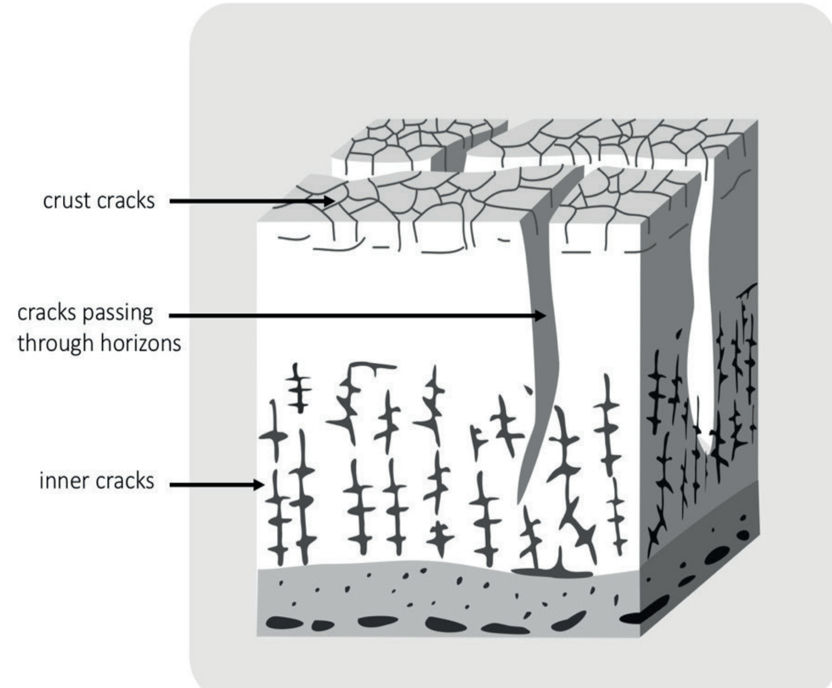

Figure 4. Soil cracks.

- clay > 52%
- peat 78% -95%.

Porosity depends on the depth of the soil layer – it is higher in the upper layers and lower in the lower layers. There is more organic matter, more activity of animals and plants, as well as greater temperature fluctuations in the upper layers of the soil.

2.3. SOIL STRUCTURE

Soil structure consists of the mutual ratio between solid particles and porous space, as well as solid particle merging into larger formations – aggregates. Water and air infiltrate evenly into soils with good structural characteristics, ensuring the growth of tree roots and the development of soil microflora. Soil aggregate destruction can cause a compacted top layer, which prevents precipitation from penetrating into the soil and promotes erosion.

Soil structure is also formed by various processes – moistening and drying out of the soil, freezing and thawing, as well as the activity of animals and plant roots. The main characteristic of the soil structure and the sign of fertile soil is the ability to resist the depleting activity of water, maintaining its shape and properties in the aquatic environment, i.e. the soil must be water erosion resistant.
Soil structure is determined by reference to the structural aggregate kind and type. There are structureless soils (soils without structure or definite internal arrangement) and structured soils (soils with internal arrangement of particles).
Structureless soils are divided into powdery and massive soils. Powdery soils include, for

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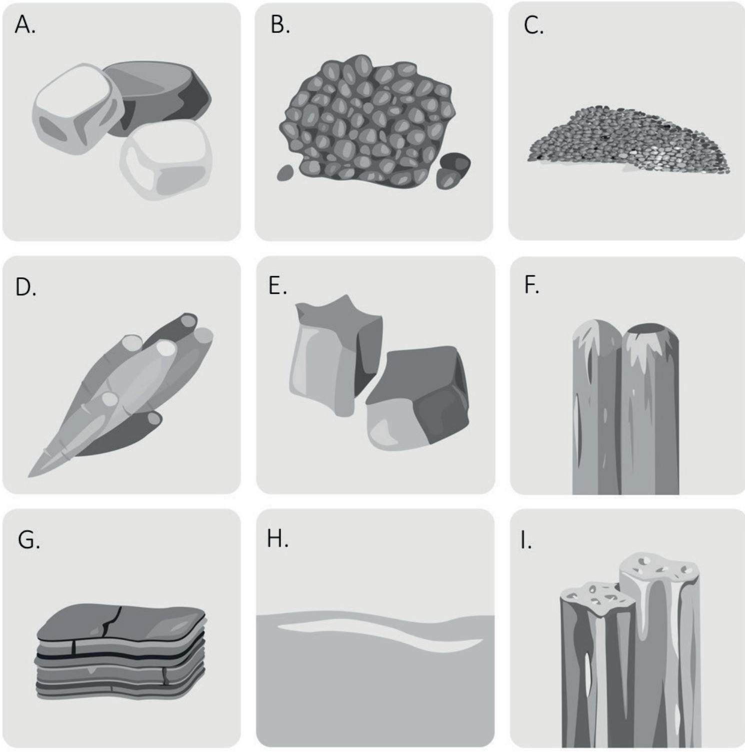

Figure 5. Soil structure aggregates, according to their shape: A. rounded; B. granular, C. powdery, D. wedge-shaped, E. angular, F. pole-shaped, G. platy, H. massive, I. prismatic.

example, dune sand soils. Massive structureless soil includes heavy, dense clay soil.
Structured soils form micro-aggregates in the process of aggregation, and macro-aggregates occur when they merge. Structural aggregates are divided according to their shape: rounded, granular, powdery, wedge-shaped, angular, pole-shaped, platy, massive, prismatic (Figure 5).
From an agronomic point of view, the most valuable is a water (erosion) resistant crumbly structure.
The most important actions to improve soil structure are:

- loosening of the soil at its optimum humidity;
- soil enrichment with organic matter;
- liming of acidic soils and gypsum treatment for saline soils.

2.4. SOIL CONSISTENCY

Soil consistency is an important indicator to be taken into account both in construction and in farming. Consistency combines properties such as friability, plasticity, stickiness and resistance to pressure. All these properties depend on the amount of clay particles in the soil. Dry, moist and wet soil is distinguished for determining the consistency of the soil.
By consistency, dry soil can be: loose, soft, slightly hard, hard, very hard, and extra hard. Consistency is determined by squeezing a piece of soil. Loose soil particles are not interconnected, while a piece of hard soil is resistant to pressure.

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The consistency of wet soil is characterized by stickiness and plasticity. Stickiness is an adhesion property of the soil in relation to another object. The stickiness of the soil under natural conditions varies depending on the amount of water in the soil and the level of destruction of the natural order.

Soil plasticity is the ability of the soil to gradually change its shape and maintain it under the influence of load. In field conditions, the plasticity of the soil is determined by twisting the soil sample in hands until ~3mm diameter "stick" is formed. Plasticity can be characterized as: not plastic, slightly plastic, plastic, very plastic. Dry soils and very wet soils do not have plasticity. Greater plasticity is observed in fine soil particles. Sand is not characterized by plasticity, while clay soils have significant consistency – they are both sticky and plastic.

2.5. SOIL MOISTURE

Water enters the soil with precipitation and very rarely - with high-level groundwater. The height of vegetation significantly affects the amount of precipitation received. It is influenced by the leaf area index (leaf surface per ground surface m^2m^{-2}). Tree crowns retain moisture; it begins to evaporate even during rain. Raindrops tend to converge on the leaves of trees, so they fall heavier and larger on the ground, thus possibly compacting the soil exposed under the tree crowns, posing a risk of water erosion.

Water infiltration into soil is determined by the soil composition, including the topography of the site (plain, slope, etc.). On a large slope, rainwater flows to the foot of the slope without infiltrating into the soil. The absorption may also be disturbed by the soil compaction, while on asphalt and concrete surfaces the absorption hardly occurs.

Evaporation of moisture from the soil under tree crowns is much smaller than in open areas with sparse vegetation and exposed soil. The layer of vegetation prevents solar energy from getting into the soil, thereby also reducing the extent of evaporation.

The proportion of water in soil is closely linked to the soil composition and minerals. Sandy soils, for example, have a small surface area on 1 gram of soil. Such soils are characterized by large void space between the solid soil particles. Clay soils, on the other hand, have a large surface area on 1 gram of soil and small space between the particles. Entering the soil, water fills the free space between the solid particles. There is a lot of free space in sandy soils and water remains on the surfaces of solid particles, while in clay soils it fills all the free space. The water in the soil is not always available to plants, for example, dense clay soils with low organic matter may contain lots of water, while plants are able to use only a small portion of it. In contrast, sandy soils that are rich in organic matter and well-aerated make nearly all water of the soil available to plants. Soils with high organic matter content are able to absorb large amounts of water.

2.6. SOIL TEMPERATURE

Soil temperature is one of the factors of soil fertility that affects the life of plants and soil fauna. Soil receives heat from solar energy and the amount of it depends on the geographical location, slope of the ground and exposure. For example, the total amount of heat received by the southern and northern slopes throughout the year varies significantly. Another source of heat is the atmosphere and precipitation. If they are warmer than the soil, then part of the heat is given to the soil.

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Thermal regime of the soil depends on the amount of solar radiation received and the type of soil. Exposed and dark soil warms up faster. It is protected from overheating by vegetation. Heat enters in the deepest layers of the soil due to its thermal conductivity. Temperature fluctuations are observed at a depth of 10-15 cm, while deeper the temperature is constant. Soil temperature affects various processes: rock abrasion, microbiological activity, chemical processes such as nitrogen nitrification, soil moisture, etc.

Soil thermal regime and its fluctuations can be changed within certain limits by the following actions:
- soil treatment (changes the color of plant blanket, affects moisture evaporation);
- soil drainage (soil warms up faster);
- soil mulching (lowers or increases the temperature depending on the mulch material);
- soil watering (lowers the temperature);
- installation of plant protection zones, reduces heat loss under the influence of wind.

2.7. SOIL EROSION

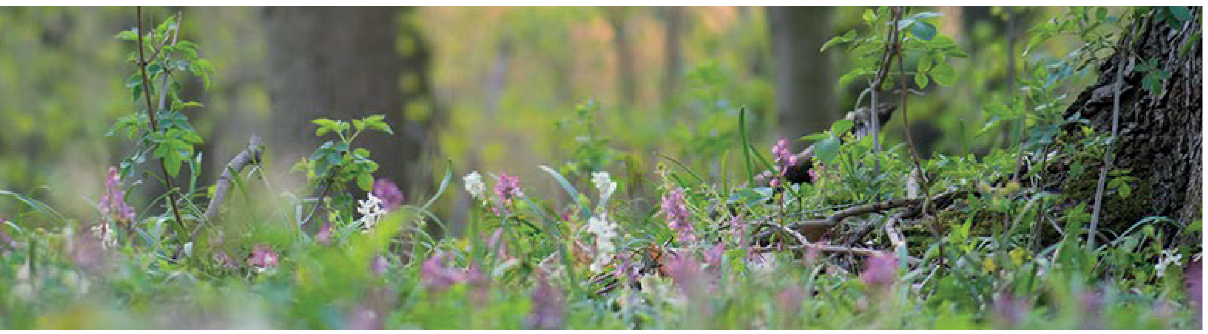
Soil erosion is a natural geological process. Human economic activity can promote, reduce or stop soil erosion.

There are three different types of soil erosion:
- water erosion;
- wind erosion;
- mechanical erosion.

Water erosion of the soil is caused by the flow of surface water over the Earth's surface. This can be caused by splashes of raindrops, a steady flow of water on the ground surface, or water can concentrate in linear streams. Larger geological erosion processes take place in more diverse terrains - as a result of water erosion, water streams form trenches and ravines.

The resistance of the soil to water erosion is determined by various factors, such as the granulometric composition of the soil, water infiltration capacity, incline of the slope, etc. Gravel sediments are the most resistant to water erosion, while loamy soils are the most vulnerable. Vegetation also affects the likelihood of water erosion: soils in forest ecosystems have the lowest water erosion potential, while exposed soil – the highest.

Water erosion not only reduces the soil fertility but can also limit the soil use. In order to avoid water erosion, various prevention measures may be taken:
- soil treatment without turning the turf;
- terrace shaping;
- recultivation of degraded lands;
- forest conservation;
- proper soil treatment (across the slope drop).



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Soil wind erosion occurs within the interaction between wind and particles in the topsoil. The occurrence of wind erosion is influenced by various factors:
- the granulometric composition of the soil (e.g. a higher risk of erosion in soils of dusty composition;
- size and location of the particular site within the landscape (higher risk of wind erosion in open landscapes),
- soil moisture (wet soils are not prone to wind erosion);
- the presence of natural obstacles (they serve as windbreaks);
- soil cover (wind erosion is unlikely in forest and grassland ecosystems).

Wind erosion can have various negative consequences, such as reduced soil fertility, environmental pollution by dust and solid particles, drainage system clogging, water pollution.

Important measures to limit wind erosion are establishment of wind protection plantings, soil treatment without turning the turf, crop rotation, or the use of various agro-forestry methods.
Mechanical erosion of soil is the movement of soil as a result of its treatment or other mechanical actions. This type of soil erosion includes soil damage caused by agro-technical treatment, warfare, landslides, as well as mining (e.g., gravel pits).

3. CHEMICAL PROPERTIES OF SOIL

3.1. MINERALS IN SOIL

The composition and chemical properties of the soil are determined by many factors: minerals, granulometric composition of the soil, processes of soil formation, human activity, organic matter, climatic and humidity conditions, as well as biological factors. The chemical composition of the Earth's crust plays a key role in the formation of the chemical composition of the soil. Chemical elements that compose less than 0.001% of soil are called micronutrients (trace elements), while elements that compose more than 0.001% are macronutrients (Table 1).
The mineral part of soil is divided into fine soil fraction (particles smaller than 2 mm) and soil skeleton (particles larger than 2 mm - coarse gravel, pebbles, stones). The solid part of the soil consists of various types of rock debris and minerals. Minerals are homogeneous, crystalline, usually inorganic substances, formed by physico-chemical processes. They are characterized by a crystal structure. Primary minerals are coarse-grained and preserved within the soil from the original magmatic or metamorphic bedrock. Secondary minerals are formed in the soil when the primary minerals undergo chemical and biological transformation creating new minerals.
Soil minerals determine the granulometric composition of the soil or the soil division according to the size of mineral particles. Granulometric composition is an essential indicator of soil fertility.
Soil granulometric composition determines:
- physical properties of the soil;
- soil air permeability;
- soil heat capacity;
- the amount of productive water in the soil;
- plant nutrient stocks.

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Table 1. Soil macronutrients and micronutrients.

SOIL MACRONUTRIENTS	SOIL MICRONUTRIENTS
Oxygen (O) - the most common element in the Earth's crust and soil. Found in minerals, organic matter, soil water.	**Manganese (Mn)** – one of the most common trace elements of the lithosphere. Important in the process of photosynthesis.
Silicon compounds (Si) - most silicon compounds form the basic mass of the Earth's crust. Found in minerals.	Copper (Cu) – is present in almost 200 minerals. Reduces the incidence of fungal diseases in plants.
Aluminum (Al) – the most common metal in the Earth's crust and soil, it forms more than 350 minerals.	**Zinc (Zn)** – is found in 66 minerals. Zinc uptake for plants depends on the amount of phosphorus, manganese and iron in the soil. Zinc is important in plant metabolism.
Iron (Fe) – the second most common metal in lithosphere, important in soil formation processes and plant metabolism. It is a component of many minerals.	**Cobalt (Co)** – is found in soil aluminosilicates. Affects the ability of legumes to fix atmospheric nitrogen.
Calcium (Ca) - a metal found in a number of well-known rocks and minerals, such as dolomite, gypsum. Important for plant growth.	**Boron (B)** – occurs in acidic igneous rocks and is easily leached from the soil. Important in plant metabolic processes.
Magnesium (Mg) – found in igneous rocks. Important in the process of photosynthesis.	**Molybdenum (Mo)** – associated with granite and other acidic igneous rocks. Important in plant metabolic processes.
Potassium (K) – important for soil development and plant growth, as it participates in metabolic processes: synthesis of carbohydrates and proteins.	**Selenium (Se)** – is present in sulfide minerals. Plants typically have selenium deficiency in acid soils.
Sodium (Na) – found in soils as part of silicates and aluminosilicates.	
Nitrogen (N) – is present in the organic material of soil. Important for plant growth.	

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Soil classification system of the Food and Agriculture Organization (FAO) of the United Nations (UN) uses the following classification of the fine texture soil composition:

- clay: 0,002 mm;
- fine silt: 0,002 - 0,02mm;
- coarse silt: 0,02 - 0,05 (0,063)mm[8];
- very fine sand: 0,05 (0,063) - 0,125 mm;
- fine sand: 0,125 - 0,200 mm;
- medium sand: 0,20 - 0,63 mm;
- coarse sand: 0,63-1,25 mm;
- very coarse sand: 1,25 – 2,00 mm

Soil particles of each size have a certain set of physical and chemical properties that play an important role in the formation and maintenance of soil fertility. For example, soils dominated by clay particles have increased moisture capacity but slowed water infiltration.

Soil properties are expressed by a three-component classification represented by a nomogram of soil granulometric composition (Figure 6).

In this nomogram there is 100% sand in the left corner, 100% clay at the peak and 100% silt in the right corner. Using this nomogram, the following basic groups of soil granulometric composition are separated: sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, heavy clay, extra heavy clay.

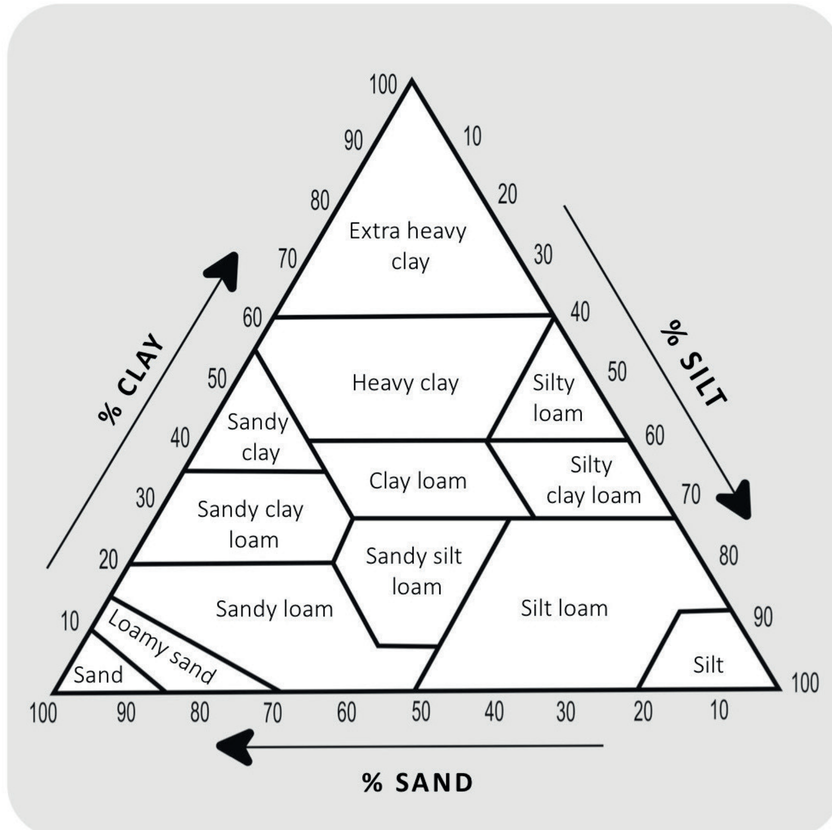

Figure 6. Nomogram of soil granulometric composition

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3.2. SOIL ORGANIC MATTER

Soil organic matter is a component of soil that is formed from residues of plants, animals and micro-organisms in various stages of decomposition. The amount of organic matter in mineral soils can range from 0.5% to 5%, while in soils rich in organic matter - up to 100%. The amount of soil organic matter depends on the factors that make up the soil: climate, vegetation, soil bedrock, topography and time.

The most important producers of soil organic matter are surface debris, dead plant roots, soil animals and microorganisms. In agricultural soils, the source of organic matter in the soil is manure fertilization, including the incorporation of green manure and plant residues into the soil.

Soil organic matter is one of the most important components affecting soil properties and soil processes. Organic matter improves the physical and chemical properties of the soil. Organic substances contain all micro and macro nutrients relevant to plants and by breaking down they become soil liquid readily available to plants. The presence of organic substances improves the soil structure - porosity increases, particle adhesion decreases, the proportion of soil air increases. As the amount of soil organic matter increases, the supply of nutrients to the soil microorganisms improves, thus generally improving the biological properties of the soil. Organic substances increase the resistance of the soil to various adverse factors and processes, such as absorbing heavy metals, pesticides, protecting the soil from freezing and erosion

The composition of soil organic matter is complex, but it is dominated by lignin residues, cellulose, hemicellulose, pectins, as well as various small molecular compounds - carbohydrates, proteins, lipids, waxes, carboxylic acids, etc.

Soil organic matter is divided according to the degree of its decomposition: humus and organic residues. As a result of biochemical processes, humus is a well-degraded plant and animal residue, while organic residue is a non-humic plant and animal residue. Humic substances form such materials as peat, sapropel, lignite, which are able to absorb large amounts of water and contain fossil carbon. The formation of humic substances or the course of humification is influenced by temperature, amount of water, microorganisms in the soil, as well as the ratio of oxygen and carbon in the decomposable organic residues.

3.3. SOIL pH

Soil reactions or pH are the negative logarithm of the hydrogen ion concentration ($pH=-\log[H+]$). The reaction of the soil solution is neutral if the pH = 7, the solution becomes more acidic if the pH is less than 7, and the solution becomes alkaline or basic if the pH is more than 7.

Soil reaction is one of the essential properties that affect plant growth. Each plant has its own optimal pH range. For most crops grown in clay and loam soils, the optimal soil pH is 6.5 - 7, but in sand and loamy sand soils it is 6.0-6.5. The soil reaction affects the availability of nutrients to plants. At the right pH, plants are more capable to absorb the nutrients of the soil. The pH range from 6 to 8 is suitable for the activity of soil microorganisms. In this range, the decomposition of organic matter takes place actively, as well as the symbiotic bacteria that fix atmospheric nitrogen are active. Depending on the pH of the soil, the availability of various micro and macro elements to plants changes, as well as the activity of soil microorganisms and fungi (Figure 7).

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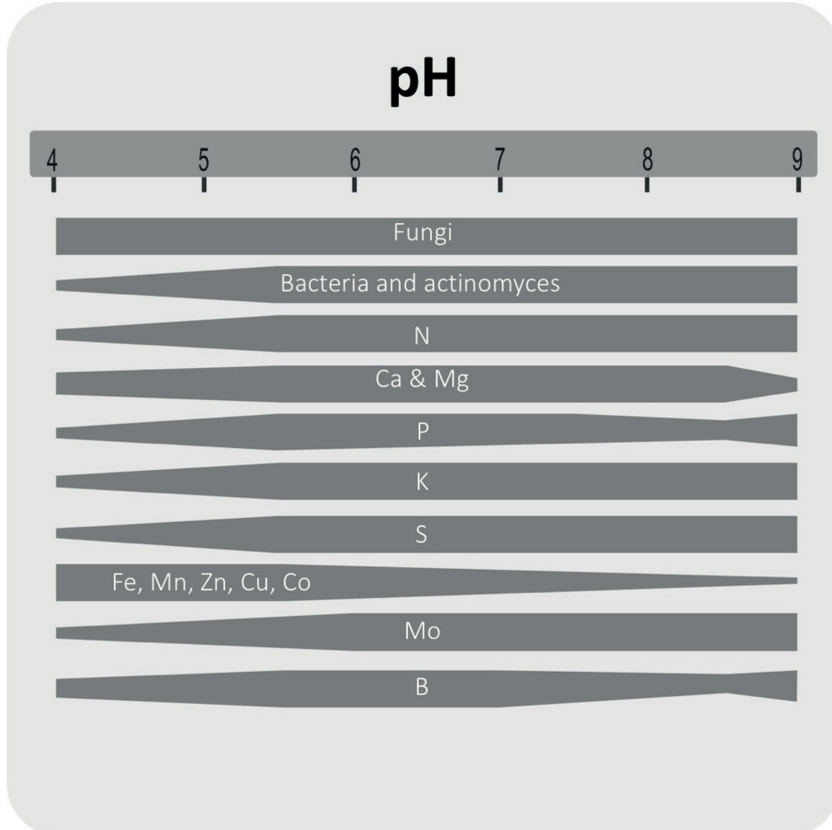

Figure 7. Soil pH affects on mineral availability for plants, as well as on activity of fungi, bacteria and actinomyces. (According to Foth D.Henry, 1990)

3.4. SOIL POLLUTION

Soil pollution is the result of human economic activity. The main polluters are industry, energetic, transport and agriculture. Soil pollution can be point source or diffuse (non-point source). Point source pollution is caused by oil spills from pipelines, landfills, petrol stations, vehicle washing, etc. Diffuse soil pollution, for example, occurs from the agricultural land treatment with pesticides, as well as from entry of various substances into the soil through precipitation. The most common soil contaminants are heavy metals, pesticides, various oil / petroleum products and radioactive isotopes.

Heavy metals are those metals with the relative density of 5 g cm^{-3} or more. Soil naturally contains a number of heavy metals, but most of them enter the soils through contamination and are toxic to wildlife. It is caused by various sources - metallurgical plants, terrain irrigation with sewage, soil fertilization and liming, landfills, as well as vehicles. Particularly high soil pollution with heavy metals is near highways, in the cities and in the vicinity of large industrial manufactures. Heavy metals tend to accumulate in the top layer of the soil also during such agricultural activities as liming and pesticide application, for example, fungicides containing copper (Cu) are used to control fungal diseases.

Elevated concentrations of heavy metals in the soil negatively affect the activity of microorganisms, and thus the availability of nutrients, as well as they have a toxic effect on plant roots and mycorrhizae, which reduces nutrient uptake. The most dangerous heavy metals for living nature are mercury (Hg), copper (Cu), nickel (Ni), lead (Pb), cobalt (Co), cadmium (Cd), also silver (Ag), beryllium (Be), tin (Sn). As soil contamination with heavy metals increases, so does the risk of groundwater contamination.

Soil contamination with oil products occur during accidents involving petroleum spills, such as from pipelines, transshipment terminals, railway areas. At and near petrol stations, oil storage areas, and abandoned military areas. Petroleum products include fuel, diesel, heavy fuel oil, lubricating oils, as well as various by-products of oil refining, such as sulfuric tar.
The migration of petrol products in the soil is affected by the soil composition and drainage properties. For example, if gasoline spills in a sandy soil, petrol products can reach layers as deep as 8 m in a short time, also creating a risk of groundwater contamination.

The main soil contaminants with pesticides are intense agriculture and forestry. Pesticides are specially synthesized chemical compounds that cause toxic effects on living organisms. Organophosphorus pesticides are relatively unstable and rapidly degradable in soil, so they are currently widely used in agriculture and forestry. Organochlorine pesticides, such as DDT, are persistent pollutants. Some of these pesticides are banned in the European Union and elsewhere in developed countries, but in some parts of Africa and Asia they are still used in agriculture.

Soil contamination with radioactive isotopes is caused by nuclear tests, accidents at nuclear power plants, processing and enrichment of rocks containing uranium and other radioactive isotopes, and improper storage of nuclear waste. One of the largest nuclear power plant accidents in the history of the world occurred on April 26, 1986 at the Chernobyl nuclear power plant, which resulted in radioactive isotope contamination in territories of most European countries. Soil contamination with radioactive isotopes can pose a threat to wildlife and there is a risk of groundwater contamination.

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4. SOIL ECOLOGY

4.1. SOIL MICROORGANISMS AND ANIMALS, THEIR ROLE

Soil biota, or living part, consists of various living organisms - bacteria, protozoa, fungi, soil algae, various animals, as well as plant roots. The diversity of living organisms in the soil exceeds that of freshwater and terrestrial organisms. Soil microorganisms - fungi and bacteria biodegrade the organic matter through biochemical processes. Larger soil animals provide mechanical shredding, loosening and transport of organic matter. Humus is formed in the interaction of microorganisms and soil animals.

Significant processes in the soil are performed by various soil bacteria. Bacteria actively break down soil organic matter. Bacterial cells can absorb only water and simple organic substances from the soil - monosaccharides, amino acids, fatty acids, glycerin, etc. In order to obtain nutrients, bacteria release enzymes, thus also breaking down large molecular compounds in chemical processes - cellulose, chitin, proteins. Soil bacteria are diverse and able to break down almost all the organic compounds found in the soil.

Soil bacteria are divided into different groups by function:

- aprotrophic bacteria that break down plant and animal residues, as well as they are used in soil remediation;
- symbiotic bacteria that work closely with plants and help absorb nitrogen (for example, legumes and gum bacteria, also white alder);
- pathogenic bacteria that cause plant damage and disease, as well as disease in animals;
- lithotrophic or hemoautotrophic bacteria or archaea, which provide their life processes by chemically altering inorganic elements, thus chemically transforming rocks;
- actinomycetes, which decompose chitin and cellulose, as well as emit the characteristic smell of compost or humus in the environment.

Soil fauna or animals can be divided into three categories:

- Microfauna (<0.2 mm)
- Mesofauna (0.2-10 mm)
- Macrofauna (> 10 mm)

Soil microfauna includes various single-celled microscopic animals *(Protozoa)*, tardigrades *(Tardigrada)*, rotifers *(Rotatoria)*. Representatives of the mesofauna are worms, e.g. nematodes *(Nematoda)* and encytraeids *(Encytraeida)*, molluscs *(Mollusca)*, as well as the most common type in soil mesofauna - arthropods *(Arthropoda)*. Characteristic soil insects are primitive and wingless - springtails *(Collembola)*, protura *(Protura)*, diplura *(Diplura)* and thysanura *(Thysanura)*, while larvae of winged insects develop within the soil - especially larvae of beetles *(Coleoptera)* and flies *(Diptera)*. The only crustaceans found in the soil are woodlouses *(Oniscoidea)*.

Soil macrofauna is formed by various larger animals that dig caves and tunnels in the soil, significantly affecting the soil structure. Macrofauna includes various spiders, harvestmen, myrapopds *(Myriapoda)*, land snails and earthworms, as well as wide range of insects: ants, digger wasps, true bugs, ground beetles, scarabs, click beetles, carrion beetles, various mosquitoes and flies.

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4.2. MYCORRHIZA, SOIL ALGAE AND FUNGI

Mycorrhiza is a symbiotic association between fungi and plant roots. It is formed by the entry of fungal hyphae or threads into the root cells of plants, thus increasing the absorbing surface. In the mycorrhizal process, plants absorb water and minerals from the soil more efficiently by the help of fungi, while the fungi receive carbohydrates from the plant photosynthetic process. Mycorrhiza is found in 80-95% of plant species. Its development is closely related to the concentration of plant nutrients in the soil. Mycorrhiza is less common in nutrient-rich as well as dry soils, although plants in dry soils are often able to survive precisely because of mycorrhiza, which increases the drought resistance. Mycorrhiza also has other ecologically important functions. In addition to plant root system, mycorrhiza forms a branched network of hyphae that bind soil particles and help shaping the soil structure. Mycorrhizal fungal hyphae are able to accumulate heavy metals, and thus lower concentrations of heavy metals reach the plants. Mycorrhiza is used to improve the growth conditions of woody plants, to strengthen dunes, and in ecological recultivation.

Parasitic, saprophytic and other fungi are also found in the soil. Saprophytic fungi participate in the breakdown of organic matter - the fungi release enzymes into outside environment, which break down complex organic matter, and absorb simple organic substances and minerals through the walls of the hyphae. Saprophytic fungi are directly involved in the formation of humus. Parasitic fungi are found in the soil at dormant state and in the form of spores. Parasitic fungi cause plant and animal diseases such as powdery mildew, root and root collar rot, fusariosis, etc. Sac fungi (such as Gyromitra and true morels), slime mold, and zygote fungi are found in the soil, as well as basidiomycetes (such as chanterelles and various “hat mushrooms”) that are widely consumed by humans.
Various algae are also found in soil. They themselves synthesize organic matter through photosynthesis. Surface algae tend to multiply on moist and exposed soil, forming a green film or peel. There are also algae that inhabit the soil water or the soil itself. Most soil algae are microscopic organisms, but when they multiply they can be seen with the naked eye (e.g. - on fields or on construction debris). Various species of green algae *(Chlorophyta)* are the most common in soil.

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II.

Soil assessment

1. THE NEED FOR SOIL ASSESSMENT

Soil and geological research are necessary before starting any green area management or improvement works. Soil assessment provides an understanding of soil properties and conditions, including possible limiting factors that may affect tree growth. Knowing the characteristics of the soil, it is possible to decide on various soil improvement measures, as well as to choose plants that are more suitable for specific soil conditions. Soil assessment can be performed by visual methods, as well as by taking soil samples and performing detailed analysis in laboratories.

Soil sampling depends on the area diversity and purpose of the study area. Soil analyzes are performed in two ways:

- collecting soil samples from the top layers in which plant roots develop
- by assessing the soil profile in the soil pits or by making deeper wells for the analysis of soil layers.

2. SOIL SAMPLING METHODS

The collection of soil samples from the top layers (approximately 15 - 20 cm deep) makes it possible to analyze the soil composition, the amount and availability of nutrients, the amount of organic matter, as well as to identify possible tree plant problems. Soil samples are collected with a special tool - a soil drill (Figure 8), or - using a shovel. The expert decides how many samples should be collected, but it is decided to collect at least 10 different samples in an area of 100 m2. If the study area is large, it is divided into smaller segments with similar characteristics, such as differently managed areas, areas with different soil granulometric composition

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(sandy and loamy soils), areas with different geographical locations (e.g., depression, slope, hilltop), as well as places with different vegetation. If the sample is collected with a soil probe or a shovel, it is important to remove the vegetation cover and spills so that only the soil is collected in the sample. Drill or dig a part of the soil with a shovel and place in a polyethylene bag for delivery to the laboratory. If the volume of the samples collected in a given area is too large to be collected in a bag, the samples are combined in a plastic bucket and mixed to obtain averages. Fill the sample bag with this mixture. The best time for sampling is not specified, but it is usually done in early summer. Sampling after heavy rains should be avoided. Soil sampling should be planned in relation to the specific problem of the trees, for example, if trees next to a street that is salted in winter show signs of stress, then soil sampling should be done in the root zone of these trees as well as where the trees are healthy. This diversification of samples will allow the comparison and observation of different soil conditions, including contamination such as salt (NaCl).

Figure 8. Collection of soil samples with A. soil probe; B. shovel.

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3. SOIL PROFILE ASSESSMENT

Soil profile assessment is used to assess soil properties in vertical layers. Such an assessment makes it possible to determine the historical management of the tree growing site and the presence of various disturbances, such as construction debris, soil compaction, etc. The soil profile is available in places where excavations have been carried out during construction, such as road or landscaping. However, such exposed areas will be rarely available. A special tool is used to assess the vertical profile of the soil - a soil auger (Figure 8), the mechanism of which allows taking a cylindrical sample at different depths. The soil profile is usually assessed at a depth of 1 to 2 m. Probe samples are placed sequentially and in depth to judge soil properties. If the study area has obviously different soil conditions, then the probing is performed in several places, for example, in a dry hill and in a wet depression.

4. PARAMETERS OF SOIL ANALYSIS

Soil assessment can be performed visually, under field conditions, while the collected soil samples are analyzed in a laboratory, evaluating various indicators. The most commonly used soil assessment parameters are soil structure, density, texture, water and organic matter content, pH, salt content and microbiological activity.

Under field conditions, **soil texture** is assessed by the so-called 'sense method', in which a small volume of soil is moistened, turned in the hands to form a cylindrical shape and its length is measured. This method is subjective.

Soil structure can also be assessed visually by describing the characteristics of soil aggregates, such as shape and size.

Soil organic matter (SOM) is described as one of the most important indicators for soil quality. It can be assessed in field conditions by color: the darker is color, the higher is soil organic matter content. More detailed analysis is provided by most laboratories. Good quality topsoil should have 3-10% SOM contents of the wight.

Soil pH indicates hydrogen ion activity in the soil solution. For the best results of pH, it is recommended to send soil samples to the laboratory. For field assessment different tools can be used: soil pH probe, litmus paper or different indicator kits.

Soil water is essential to assess to identify plants stressed from water deficits or too much water. The amount of water can be measured in various ways: rough estimation by observing physical indicators; using electric soil moisture meter, tensiometer and others.

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III.

Soil modification and managment

1. SOIL MODIFICATION

In natural conditions, soil develops by the interaction of various factors, determining the physical and biochemical content of the soil. However, such processes may be significantly altered in urban areas, where natural disturbances are strengthened by the anthropogenic factors. Therefore, an information about most commonly applied soil treatments, which can improve the health and longevity of urban trees, is gathered in this section.

2. SOIL AMENDMENTS

The incorporation of amendments into the soil is relatively easy low-cost approach to improve the soil matrix, which reduces soil compaction, thus aeration and water conductance can be facilitated. Soil amendments can be both organic and inorganic. Organic materials are used for the increasing of soil fertility, as well as promoting of bioactivity in the rhizosphere, and adjustment of bio-chemical properties, such as the reaction (pH). However, the fertility and the pH can be notably adjusted by the use of inorganic amendments, which can improve the content of minerals. The application of inorganic soil amendments for urban trees due to improve the mechanical properties of soil, on which the porosity and bearing capacity depends. Nevertheless, the application of appropriate amendment should be considered according to soil requirements of target species of woody plants that are planned to be established or recovered.

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3. ADJUSTING pH

One of most important soil requirements of plants is the pH, which changes can be the limitation of one or another woody plant even under considerably favourable growing conditions. Therefore, particular soil requirements should be followed during forming new plantings. Yet, the effect of inappropriate pH may be observed as a long-term decrease in vitality and subsequent growth performance. Thus, in case of symptoms of tree dieback, the tree assessment would be significantly improved by including the test of soil pH, which can be easily performed either by instrumental or chemical methods in situ. On such information, the choice of appropriate materials and amounts for acidifying or alkalizing of soil can be done.

4. SALT-AFFECTED SOILS

Increased concentration of salt in soil is a common problem for urban trees, especially in regions with winter frost, where salt is being applied on streets to prevent the formation of glaze. Also, this is a problem in the aridic regions where soil evapotranspiration exceeds precipitation, thus allowing the sedimentation of sodium containing minerals into the upper layers. However, there are species of woody plants that can tolerate increased soil salinity, thus they can be planted in areas with such risk. In case the increased soil salinity appears for existing trees, a method of bioremediation can be applied. This includes the plantation of salt-tolerant plant species that accumulates salt or they provide the shading for the top-layer of soil. Thus, reducing evaporation and promoting infiltration rate of surface water. However, most effective short-term approach is a heavy irrigation that leaches salt. This must be combined with adding of gypsum that replaces sodium.

5. MICROBIAL INOCULANTS

In urban areas, intensive anthropogenic activities may cause disturbances to soil microorganisms as well, thus reducing their positive contribution in providing of suitable growing conditions of woody plants. In case of soil impoverishment, soil microbial communities are possible to be restored along with overall enrichment of soil with both organic and inorganic amendments. However, most effective way would be the use of commercial products which contain microbial inoculants meant for certain application – promotion of plant growth or protection against pathogens.

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6. MULCHING

Mulching is considered to be the most widely used method in maintenance of soil quality of greeneries. Material for mulching is easy to be obtained and applied, however it must be free of admixture that might cause a transfer of pathogens, pests or weeds. Along with the reach of main goal of mulching – regulation of soil respiration and evaporation, a development of certain pathogens might be limited by the use of appropriate mulching material (e.g. obtained from bark or wood of certain species of woody plants). A thickness of mulching has to be in accordance with the desirable result, such as prevention of weeds or water retention in the soil, which requires thicker layers to be applied. However, weed control prior the mulching and sufficient watering/rainfall would allow to make thinner layers of mulch. It is important to be kept in mind that thicker layers of mulch slower the rate of soil, as well as root respiration, therefore mulching of root collars of woody plants.

Fertilization

In many cases, fertilization occurs along with the use of amendments and mulch. However, specific compounds to increase the fertility of soil can be used in accordance with the results of nutrient testing.

7. TILLAGE

Insufficient aeration is one of most common problems of urban soils, which develops from lack of soil organisms and increased mechanical influences. The dealing with such a problem can be done by various technical approaches, adopted from agriculture or greenkeeping of golf courses. However, such treatments may cause notable damage to root systems of urban woody plants, therefore the potential impact of each technique must be evaluated.

7.1. MECHANICAL TILLAGE

Mechanical loosening of the soil is highly effective method to improve aeration and water infiltration capabilities of the soil. However, the effectiveness of such approach is determined by relatively deep penetration, which might be harmful for root systems of woody plants. Therefore, mechanical loosening of the soil must be done before the tree plantings.

Radial trenching and vertical mulching

The formation of radial trenches from the perimeter of the projection of the canopy towards tree stem may effectively improve soil aeration and water infiltration properties without causing a serious root damage. Often such trenches are filled with ether organic or inorganic amendments that can diverse soil matrix and provide nutrients.

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7.2. AIR TILLAGE

Within a root zones of existing trees, a method of air tillage is recommended to loosen soil, as such approach is considered to cause less harm for roots. Under the compressed air, medium and coarse roots are not damaged, however absorptive roots and root tips are removed. Therefore, the use of such method should be avoided in the peripheral zones of roots.

7.3. PRESSURIZED FRACTURING

Pressurized fracturing of compacted soils, also called as air injections, can be done with specifically developed devices that are installed into various depths of soils. Even hardpan layers can be fractured, however air injections are considered to be short-term solution (Figure 9).

Figure 9. Soil pressurized fracturing. Photo by J.Ozols/LABIE KOKI

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8. IRRIGATION

Accurate irrigation is known to be a key-action in urban tree management. A large variation of methods and technical approaches are available staring from water bags till the centralized watering systems. However, there are few certain aspects that must be followed to maintain the effectiveness. It is important to restore sufficient tree water status before the active phase of transpiration – midday. Thus, watering should be done during the nocturnal phase, when absorbed water can be integrated in cell formation and stored to respond to the atmospheric demand next day. The amount of required watering increases by the air temperature, tree size and Available water capacity of a soil. However, in case of limited water resources, precise watering can be done accordance with ecophysiological measurements of stress level. In general, watering must be focused on the possible areas of absorptive roots, keeping soil layers of 25-50 cm moist but avoiding oversaturation, which may cause a hypoxia.

9. DRAINAGE

Oversaturation of soil prevents aeration, thus plants are subjected to wilting under anaerobic conditions. To avoid such problems, few basic actions, such as reduction of watering and the change of the micrography to create the run-off pattern for surface water, can be done. In lot of cases drainage must be installed in larger areas, connecting neighboring systems. Such management actions can be very costly. However, the choice of the species of woody plants that are suitable for such conditions is crucial in establishing a greenery in the areas with permanently high ground-water level.

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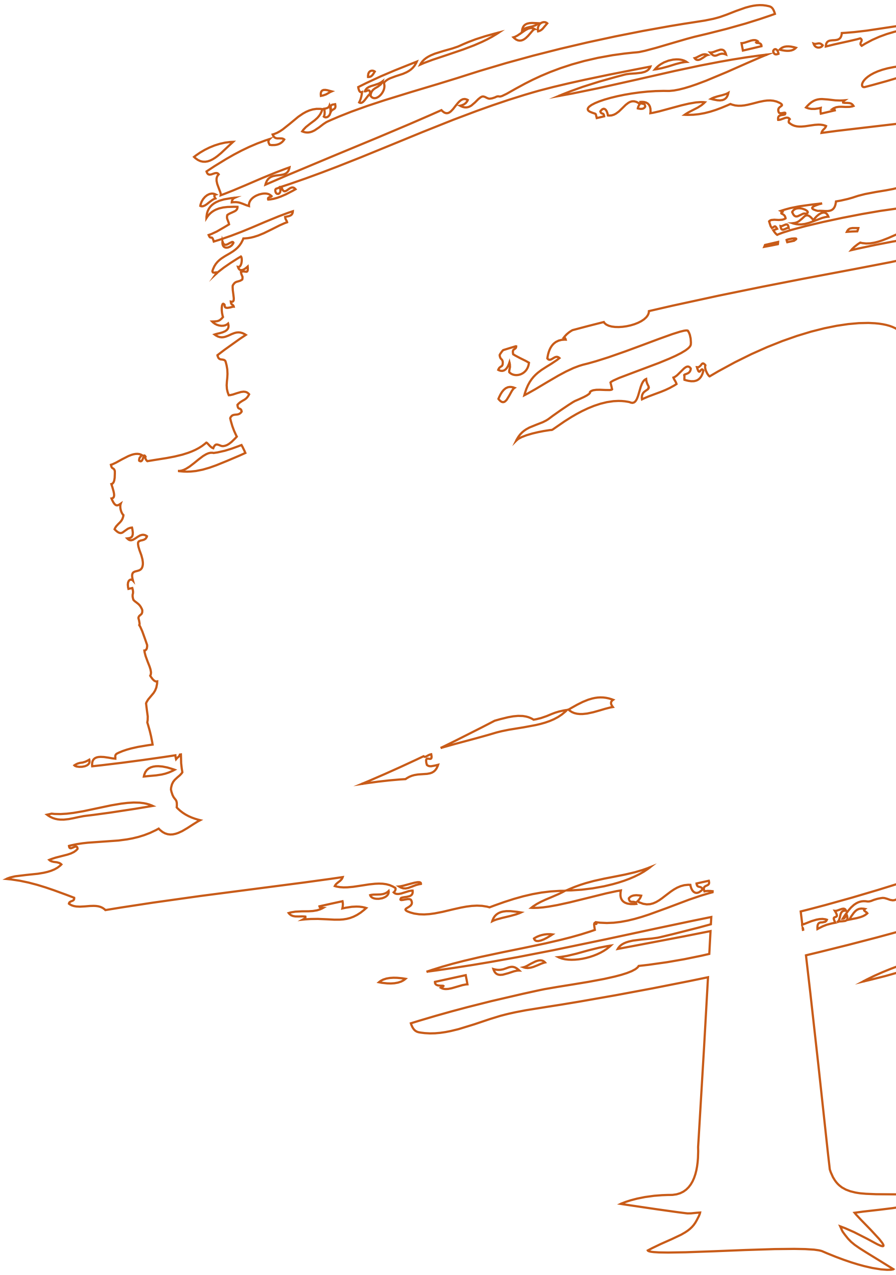

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