SOILS

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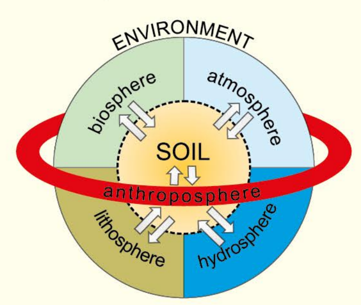
The upper, weathered, solid mantle of the Earth is called the pedosphere which resulted from complex influence of soil forming factors (parent material, topography, climate, living organisms, human activities, and time) and soil forming processes at the zone of interactions of the lithosphere, atmosphere, hydrosphere and biosphere 1, as well as reflecting variations and changes of these natural components. Soils are active and passive factors in most natural cycles and processes.

1 COMPLEX RELATIONSHIP OF THE SOILS AND THE ENVIRONMENT



The solid phase of soil comprises of particles of different size, shape and spatial distribution while air, water (soil solution), roots and other living organisms occupy the pore space. Soils are very complex in nature and vary in space and time, which is reflected by distinct patterns on the surfaces and stratifications (horizons) in the subsurface.

Soils have three important properties, namely:

- Fertility; the ability to supply the essential elements (air, water and nutrients) of life,
- Natural resilience; capacity to buffer influences and renew itself, and;
- Capacity to perform other important soil functions.

Based on the above properties, soils are one of the most essential renewable natural resources, requiring rational use, conservation and awareness from the human society.

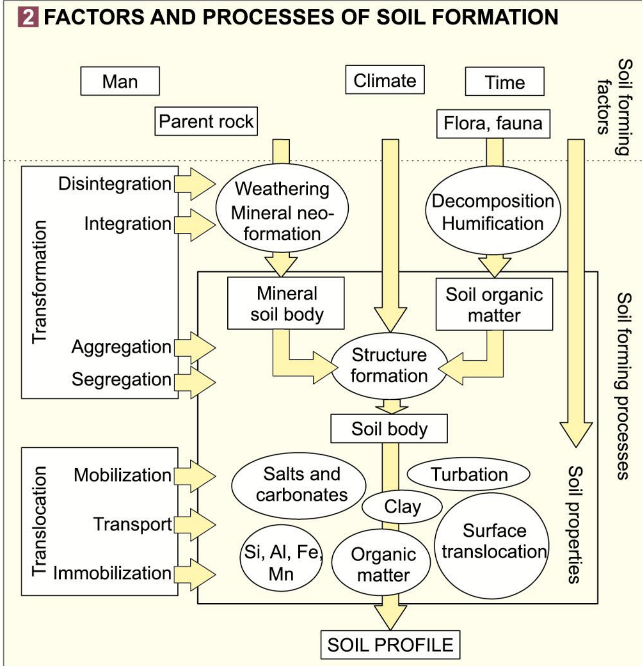
The role of soil and soil functions

Soil is a multifunctional natural resource. Its main functions and importance can be summarized as follows:

- Soil is a *conditionally renewable natural resource*. During rational biomass production it does not change irreversibly, its 'quality' does not decrease unavoidably or fundamentally. However, its renewal does not occur automatically. The maintenance of its functionality requires permanent scientifically proven methods such as rational land use, soil conservation, agrotechnics, remediation and reclamation.
- Soil is a reactor and transformer, integrating combined influences of other natural resources (solar radiation, atmosphere, surface and subsurface waters, deeper geological strata, biological resources), providing a life medium for microbiological activities and a natural habitat for vegetation and cultivation of crops. Thus, it can be considered as a huge *biological reactor* of nature, which is a vital element to life on Earth and in turn an irreplaceable mosaic of the biosphere.
- Soil is the *most important medium for biomass production and the primary food source of the biosphere*. Water, air and plant nutrients are simultaneously present in this poly-disperse system, enabling it to more or less satisfy the very same ecological requirements (water, air and nutrient supply) of living organisms, natural vegetation and cultivated crops.
- Soil is a major *natural store of heat, water, plant nutrients* as well as *wastes of* ever increasing and manifold *human activities* (production and social development). Stored water and plant nutrients ensure – to a certain extent – the continuous moisture and nutrient demand of living organisms (biota) and plants for shorter or longer periods without any additional supply. It can moderate the risk or decrease the harmful consequences of extreme moisture situations such as floods, waterlogging, over-moistening and drought.
- Soil is a *high capacity buffer medium of the biosphere*, which – within certain limits – may moderate the harmful consequences of various negative stresses caused by environmental factors such as extreme thermal, moisture or pH conditions, weathering products with unfavourable chemical composition or human activities; for example improper land use, agrotechnics, industrial production, rural and infrastructural development, raw material production, open mining and pollution. Society is becoming more and more compelled to use and take advantage of this soil function. Additionally, they even misuse it more overlooking that buffer systems have strict tolerance limits that should be adhered to.
- Soil is a huge *filter and detoxication system* of nature that may prevent the deeper horizons and subsurface waters from becoming contaminated by various pollutants deposited on the soil surface or put into the soil, although this often implies with giving up its own cleanness. Social development more often presses the utilization of this function though this is actually the temporary disposal of a 'chemical time bomb'.
- Soil is a significant *gene reservoir for the biosphere*, which plays an important role in the preservation of biodiversity, as a considerable proportion of living organisms live in soil or are directly/indirectly closely related to) soil.
- Soil is the *conservator of natural and human heritages*. It is like an 'open book' for specialists, giving evidence of past geological events and the life, perishment and history of former civilizations.

All of the above listed functions are essential, their importance, significance and 'relative weight' compared to each other has greatly changed in space and time during the history of mankind and is presently undergoing changes as well. The place, time, method and rate by which one or certain functions are used by society depend on the given social-economic conditions, the aims and expectations of made political decisions. In many cases the character (spatial and temporal variability, changeability, stability, controllability; boundary conditions and limitations) of a certain function has not – or not appropriately – been taken into consideration. This has resulted in irrational soil use, over-exploitation, miscarriage of its renewability, reduction in efficiency of one or more soil functions, and – in certain cases – triggering serious environmental deterioration in the past, and – without adequate counteractions – in the future as well.

2 FACTORS AND PROCESSES OF SOIL FORMATION



Soil forming factors and processes

Numerous *soil forming factors* 2 have played a role in the formation of the present heterogeneous soil cover of the Carpathian Basin. These factors include but are not limited to:

- *Geological conditions:* The 'parent rock' of the Basin, serving as the basic material of soil formation, is of relatively young geological formation. For example, Tertiary or older sediments of the Pannonian Sea or of the sweet-water lake were formed due to disconnection; quaternary loess and loam (deposited partly onto dry surfaces, partly into water or waterlogged areas during the Pleistocene and later transferred repeatedly), aeolian sand transported by wind in the Holocene, alluvial sediments originating from river water (fluviatile) activity, and colluvial deposits resulting from lateral erosion.
- *Climatic conditions:* Due to the three – Atlantic, Continental and Mediterranean – climatic effects, particularly high spatial and temporal variability, extreme climate and weather (making prediction, modelling and prognosis difficult) are characteristic of the Basin.
- *Relief and hydrological characteristics:* Hydrologically and hydro geologically during a practically closed basin, a negative water balance of lower lying plains is typically equilibrated by horizontal inflow (surface runoff, seepage into the three-phase zone and groundwater flow). This results in accumulation processes within the substance regime, as material is transported towards the lower lying areas by surface runoff though surface water does not evaporate in the process.
- *Natural vegetation, which has practically disappeared (or is hardly retraceable):* the Basin is characterized by forests, grasslands and wetland ecosystems of diversified appearance, composition and state ensuring different surface cover and biomass production. Their former complex role can be detected in soils developed under their influence, but by now they have declined, become strongly modified or even disappeared. Their former influence is reflected by the terminology of the Hungarian soil classification system: forest soils, chernozems, meadow soils, peats and soils of swampy forests.
- *Many physical activities of man:* deforestation (the use of timber for different purposes or for extension of agricultural fields); ploughing of natural grasslands (extension of agricultural farming areas), over-grazing on the remaining grasslands, river control, water regulation (surface and subsurface water management on waterlogged arable lands, irrigation of natural vegetation and cultivated crops for their optimal water supply), more intensive and manifold agro technical measures (cropping pattern, crop rotation, soil tillage, organic and mineral fertilization, chemization and complex mechanization) and finally, soil reclamation and amelioration if required for increasing yields of intensive agricultural production. Soils of many areas are influenced by the consequences of rural and urban development either in the form of components (extraneous materials, wastes and impermeable layer) or processes (accumulation, relocation and pollution).

The combined influences of soil forming factors determine the *soil forming processes* 2 occurring in certain areas of the world, and transform the parent rock into soils consisting of distinct soil horizons. The main soil forming processes resulting in the development of the varied soil cover and its characteristics are as follows:

Conditions of forest soil formation: cooler climate (relatively high precipitation, cooler summers, moderate evaporation, positive water balance, precipitation exceeds evapotranspiration) and low water table (although it has only a negligible influence on soil forming processes). It is characterized by the determinant role of downward flow of solutes within the soil profile, the significant influence of leaching processes (their rate depends primarily on precipitation and on the quantity of water infiltrating into and through the soil profile), and the characteristic three-layered soil profile: A (leaching) horizon – B (accumulation) horizon – C horizon (parent rock). Forest soils mainly occur in areas with cooler climate, along wet mountain ranges and hilly areas as well as on the foothills areas.

Conditions of chernozem soil formation include continental climate (warm, dry summers, cold winters i.e. two biological 'stops' in the organic matter cycle) and low water table (having only negligible influence on soil formation processes). Its characteristics include, equilibrium of moisture and substance balance (regarding the entire soil profile), periodical water and substance migration in the soil profile or in the root zone, thick and gradually terminating humus layer (in accordance with the root characteristics of the original steppe vegetation). Chernozem soils mainly occur on loess ridges were the groundwater table is low.

The *conditions for meadow soil formation* include continuous influence of high non-stagnant groundwater with low salt content plus the occurrence of hydromorphic processes. Their characteristics are: the water balance is kept at equilibrium with unsaturated flow, a two-directional, dominantly upward water and substance movement in the soil profile and accumulation of soluble matter (i.e. carbonates). Due to the influence of water saturation, reduction and oxidation processes; this results in a rust brown variegation and greyish soil horizons. Meadow soils mainly occur on low-lying areas with high groundwater table, but good runoff conditions and non-stagnant groundwater i.e. where the groundwater has low salt content and favourable ion composition (as during its horizontal movement it may repeatedly undergo dilution).

Condition of salt accumulation, salinization: it is the permanent influence of the high, non-stagnant, saline groundwater. Its characteristics are similar to those of the meadow soil; however they include an addition of the accumulation of water soluble salts in the soil profile as a determinant. Salt affected soils occur on low-lying areas with high groundwater table, poor natural runoff conditions, with stagnant and saline groundwater.

3 SIMPLIFIED CLASSIFICATION KEY TO THE SOIL TYPES

Criteria	Soil type (WRB)	Traditional genetic equivalent
Soils having organic horizon(s) that consist of undecomposed or partially decomposed organic residues (OC ≥ 20%), with a thickness of ≥ 40 cm, starting ≤ 40 cm from the soil surface	**Peat soils** (Histosols)	*Sphagnum peats, meadow peats, ameliorated peats*
Other soils under intensive anthropogenic influence that resulted in the admixture of organic/mineral materials, in the formation of new soil horizons/layers, or in the transformation/alteration of the original soil horizons	**Anthropogenic soils** (Anthrosols, Technosols)	*Newly introduced soil type*
Other soils having continuous hard rock starting ≤ 10 cm from the soil surface	**Stony skeletal soils** (Leptosols)	*Stony skeletal soils*
Other soils having continuous hard rock starting ≤ 25 cm from the soil surface, or high amount of coarse fragments (fine earth < 20%) to a depth of 75 cm of the solum or to a shallower contrasting layer	**Lithogenic soils** (Leptosols)	*Gravelly skeletal soils, rendzinas, erubase soils, rankers*
Other soils with a high content of exchangeable sodium (S% ≥ 15) or sodium and magnesium (Na + Mg > 25%), and a typical dense, columnar structured subsurface horizon within 1 m from the soil surface	**Solonetz soils** (Solonetz)	*Meadow solonetz soils, steppe meadow solonetz*
Other, alkali soils with evaporating moisture regime and soluble salt accumulation horizon (EC ≥ 8 dS/m) at or close to the soil surface (within 50 cm)	**Solonchak soils** (Solonchak)	*Solonchak and solonchak-solonetz soils*
Other, heavy clay soils (clay 30%), shrinking and swelling due to alternating dry and wet conditions, with special morphology (slickensides, wedge shaped aggregates, cracks that open and close periodically)	**Swelling clay soils** (Vertisols)	*Newly introduced soil type. Members from several soil types (mostly heavy meadow, alluvial and erubase soils)*
Other, ground water influenced soils with periodic reducing conditions and expressed gleyic colour pattern (grey matrix with red mottles) starting within 40 cm from the soil surface or under a very dark OC-rich surface horizon	**Meadow soils** (Gleysols, Phaeozems)	*Meadow soils and gleyic other soils*
Other soils, having high amount of $CaCO_3$ (calcium carbonate equivalent ≥ 40%) within 50 cm from the soil surface	**Carbonate soils** (Calcisols)	*Humus-carbonate soils, some rendzinas*
Other soils, having a deep, dark, humus-rich (OC ≥ 1.5%) surface horizon with high base saturation, good soil structure and intensive biological activity	**Chernozem soils** (Chernozems, Kastanozems)	*Chernozem and intergrade chernozems*
Other soils with higher clay content in the subsoils than the surface horizon(s) as result of leaching and clay illuviation. The clay accumulation horizon within 1 m from the soil surface contains ≥ 1.4 times more clay than the leached horizons	**Clay accumulation soils** (Luvisols)	*Brown forest soils with clay accumulation*
Other soils having a weighted average texture class of sand or loamy sand over a depth of 1 m from the soil surface, or to a depth of a cemented or indurated layer, whichever is shallower	**Sandy soils** (Arenosols)	*Shifting and humic sandy soils*
Other, moderately leached soils, in early stage of development, but already showing alteration in colour, soil structure compared to the parent material	**Brown earth** (Cambisols)	*Brown earth and some lithogenic soils*
Other, stratified soils of transported materials of various origin. Stratification is evidenced by variation in texture/coarse fragment content, different colours or non regular depth distribution of organic matter	**Sediment soils** (Fluvisols)	*Alluvial and colluvial soils*
Other soils, generally shallow, weakly developed soils developed on unconsolidated parent material or on fragmented hard rock	**Barren earth** (Regosols)	*Barren earth and eroded other soils*

Classification and characterization of soils

The genetic soil classification system elaborated by Pál Stefanovits, István Szabolcs, Ferenc Máté and their co-workers grouped soils that developed under similar soil forming factors and processes into specific soil types and merged these soil types into main soil types according to the geographical principles. Map 10 provides the information on the distribution of soils according to the traditional genetic system (pages 90–91).

On international forums, information and data exchanges are based on international standards and typologies. The tool for comparing and correlating units of national classification systems is known as the *World Reference Base for Soil Resources* (WRB), which was created by the working group of the *International Union of Soil Sciences*. The WRB soil classification system comprises 32 different Reference Soil Groups. This classification is performed by the application of a key; which is not based directly on soil forming processes but on the measurable and observable results of soil formation, acknowledged as the *diagnostic horizons, properties and materials*.

The traditional classification reflects the genesis of the soils, however often lacks the objective and numerical information required for the practice or the classification and internationally correlated processes. As result of modernization efforts of the genetic system, stronger definitions, limits and a classification key were introduced. The modernized system has not yet been officially authorized, although it has been strongly discussed and applied in educational as well as professional circles. The classification key indicating 15 units (soil types) of the modernized system is presented in Figure 3. The soil types are indicated by the use of bold letters, complemented with the correlated WRB reference soil groups in brackets and with the equivalent units of the traditional genetic system and finally, given in italic letters in separate block letters.

VII.

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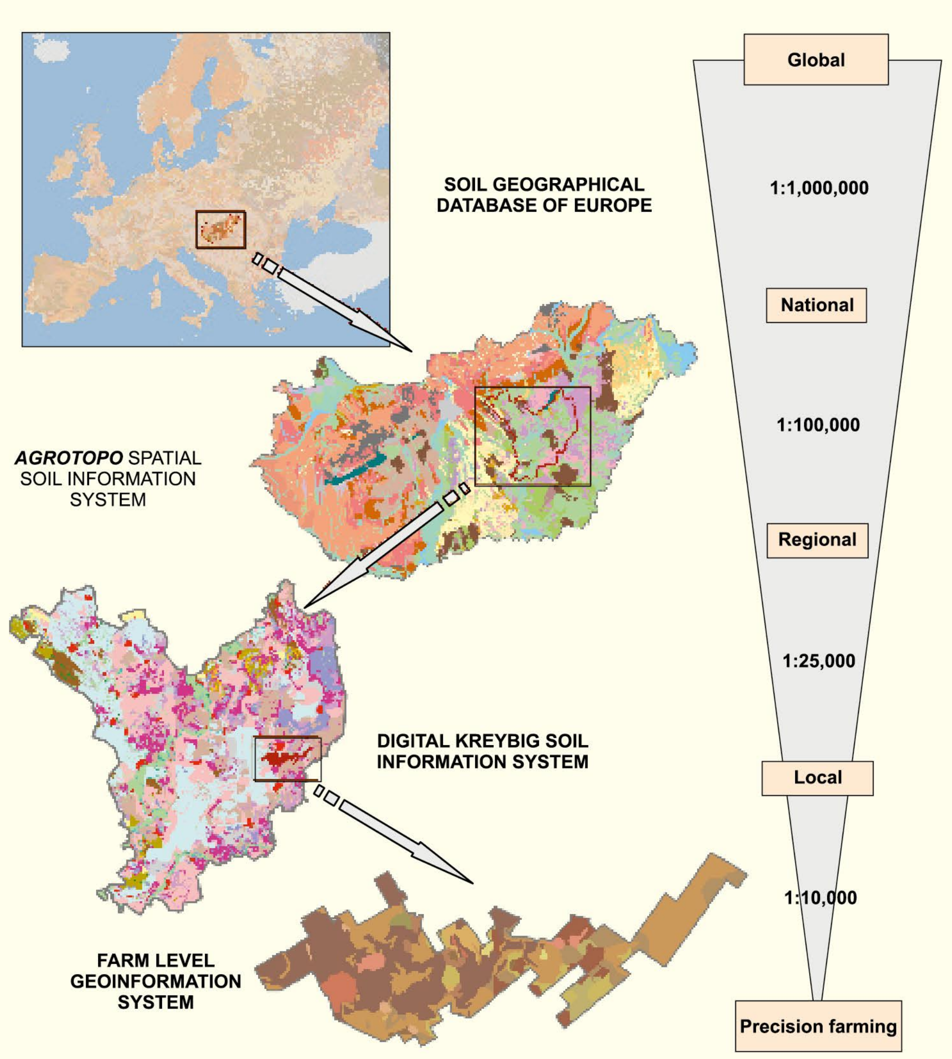
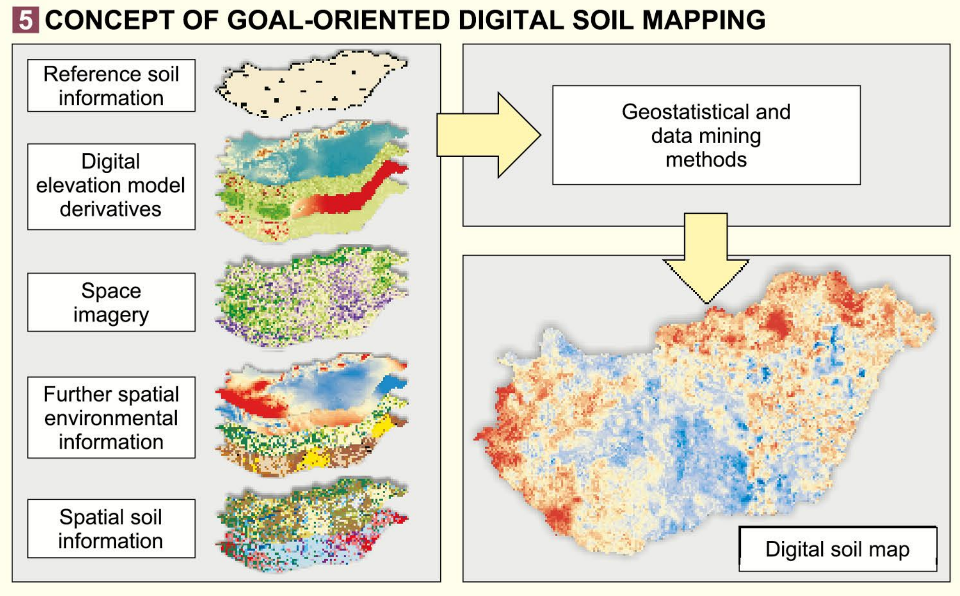
4 SPATIAL SOIL INFORMATION AT DIFFERENT SCALES



5 CONCEPT OF GOAL-ORIENTED DIGITAL SOIL MAPPING



Spatial characterization of soil mantle and soil mapping

The goal of soil mapping is to reveal and visualize the spatial relationships of thematic knowledge related to the soil mantle. Soil maps are thematic maps, whereby a theme is determined through specific information related to the soils. These can be primary or secondary (derived), quantitative or qualitative properties as well as features characterizing functions, processes or services of soils. There are two basic and virtually contradictory but rather complementary concepts used for the characterization of spatial variability of soils. One approach builds essentially on similarity and it represents the soil mantle with mapping units of homogeneous (or predictable) composition. Its cartographic realization is a classic soil map, which has extensive traditions. According to the inherent model of these maps, at the given spatial resolution, soil properties within the mapping units are either homogeneous or heterogeneous but in a cartographically unmappable way thus there is discontinuity in the mapped soil feature at the borders. The other approach emphasizes the continuous spatial variation of soil properties. The mapped soil property is predicted by the use of cells and the spatial resolution is determined by the cell size.

In Hungary large amounts of soil information have been collected through of soil surveys, observations and mappings carried out by soil science methodologies and practices. The goal and methodology of subsequent soil mappings differed, as a consequence, different mapping goals led to stressing of dissimilar soil features. The maps were compiled at various scales from farm to national level 4. The smaller scale, synthetized maps provide national coverage, while larger scale ones essentially do not cover the whole country. In the last quarter century, a gradually increasing proportion of soil related data has been digitally processed and organised into various spatial soil information systems. The first widely used national spatial soil information system was *AGROTOPO*, which was elaborated at a scale of 1:100,000 by the digital processing of the agro-ecological mapping units, which had been delineated in the frame of a project titled: 'Assessment of the Agro-ecological potential of Hungary.' The spatial database provides a suitable data source on both regional and national levels.

Larger scale map based soil information is also awaited by numerous fields of interests (environmental protection, land evaluation, precision farming, soil protection, etc.). The formerly compiled reconnaissance and large-scale practical soil maps provide suitable background to fit this requirement after their digital processing and publishing in proper Geographic Information Systems (GIS) environment that are applicable for a wider audience. GIS adaptation and digital reambulation of the legacy information collected during the countrywide 1:25,000 scale, practical soil mapping programme – hallmarked by L. Kreybig – in the form of the Digital Kreybig Soil Information System (DKSIS) played a specific role being spatially the most detailed, national map based legacy soil data set.

DKSIS is based on the data provided by Kreybig survey, and at the same time it is a national spatial soil information system supported by the possibilities provided by GIS. DKSIS is forming dynamically according to the changes in demands, making possible it more flexible and has a multipurpose utilisation in numerous goal specific applications, which are based on digital soil mapping procedures. The next level is represented by the 1:10,000 scale genetic and thematic soil maps prepared for about one third of the area of Hungary between 1960 and 1970, together with the soil information collected within the framework of the National Land Evaluation Programme, which may provide utilizable spatial soil information at farm and plot level.

Demands on spatial information related to state, processes and functions of soil are increasing. The existing maps, data and systems served the society for many years however the available data are no longer fully satisfactory for recent developments in policy making. There were numerous initiatives for the digital processing, completion, improvement and integration of the existing soil datasets.

A soil map is an object specific spatial model of the soil cover, whose compilation is dominated by the consideration of soil forming processes. There have been significant and essentially concurrent changes concerning three central elements of this definition. The growing and spread of digital soil mapping in the last decade can be attributed to the effects of these changes. The framework of Digital Soil Mapping 5 involves spatial inference of the information collected at sampled points based on ancillary environmental variables, related to soil forming processes, with exhaustive spatial coverage. The activity of DSM goes beyond mapping purely primary and secondary soil properties, the regionalization of further levels of soil related features (processes, functions and services) is also targeted. The majority of the maps presented in the *Soils* chapter were compiled applying the new, digital soil mapping technology.

The territory of the Carpathian Basin and its vicinity, the Carpatho–Pannonian Area is shared by 12 countries. Unfortunately, the quantity and quality of reference soil data, which is available in Hungary is not affordable for the whole area of the region due to objective reasons. Consequently, the maps of *Soils* chapter – except for one – cover only the actual area of Hungary. By the aid of the internationally accepted WRB system, together with the internationally available data necessary to its application, the elaboration of the soil type according to the WRB classification became possible, even with coarser spatial resolution as compared to countrywide maps 7.

The soils of the Carpathian Basin

The World Reference Base nomenclature is used to describe the soils of the Carpathian Basin, which is located at the Eastern edge of the brown forest soil zone. Due to its basin location surrounded by high mountains, its climate is more continental than one would expect of the geographic region. Therefore, Chernozems is also a zonal soil type for the plain areas. The soil association of Hungary is more similar to the areas east from Hungary and represents a distinct soil island in Central Europe. The variability of the soil resources 6 is further increased by the variable terrain and parent material as well as the anthropogenic impacts.

The mountain ring is characterized by relatively young soils like Cambisols and Leptosols, and some older ones on the stabile surfaces, like Luvisols and Podzols. Their spatial share and their properties are defined by the variable parent material and the terrain position.

The crystalline rock dominated higher parts of the Northwestern Carpathians are covered with Leptosols, bare rocks, and the so-called Micropodzols–shallow soil with very thin layers or Albic- and Spodic-like materials that are not yet developed enough to be Podzols. Their texture mainly comprises sand with high amounts of rock fragments. Soils on shales are very shallow due to intensive erosion, low infiltration and extremely steep slopes. These soils are very acidic with low base saturation and low amount of organic material. Significant organic material concentration occurs only on the low slope surfaces with high water inflow. Thus, saturation limits organic material decay which results in possibly strong accumulation of organic material.

In the less sloping regions, lower elevated areas under coniferous forests mainly have Podzols with variable depths, associated with Umbrisols and Cambisols. These soils are very acidic, highly leached with low base saturation and light texture with huge rocks fragments, and much of undecomposed organic matter on the surface. The deciduous forest zone has mainly Luvisols and very acidic Alisols.

The higher regions of limestone cliff zone mainly have rendzic Leptosols and bare rocks on the steep outcrops. These soils are not that leached and acidic because of the buffering capacity of the mixed limestone fragments. The texture is becoming finer and the organic matter content is starting to increase. The less sloping areas with less erosion have deeper soils, mainly Luvisols and Cambisols on the freshly weathered younger surfaces.

The lower relief sandstone ridges have quite complex soil associations of Cambisols, sandy Alisols on the deeply weathered strata and Umbrisols on the shallower surfaces. Podzols are also common on the stabile surfaces. The soils of rhyolite and andesite have always coarser, lighter textured Umbrisols and Cambisols, and Luvisols on the deeply weathered parent material. Soils developed on basalts are mainly shallow Leptosols or Phaeozems with higher clay content and higher amount of fine sand size disintegrated and not yet weathered rock particles. Moreover, the base saturation of organic matter content is increasing as well. Bare rock surfaces are not that common, because of the lower erosion rates yield better living conditions for the covering plant. The gently sloping areas have Luvisols with much better chemistry for plant support.

The lower inner arch of the Northwestern Carpathians, the North Hungarian Range has very complex geology. One can find the whole range of volcanic stones of rhyolite, andesite and basalt together with the consolidated sedimentary limestone, sandstone, shale and the unconsolidated Tertiary sandy and clayey sea sediments as well as quaternary loess redistributed by mass movements or by erosion along the slopes. The carbonate rocks are covered by Rendzic Leptosols. These soils have high sand fraction inherited from the sand stone layers already eroded away, but left their remains trapped in the depressions of the undulating limestone karst. These Leptosols are associated with Luvisols and Cambisols. Despite the high buffering capacity, these soils are often extremely acidic due to the very intensive leaching. The acidity decreases on the deeper profiles, where leaching is much less expressed and typical Luvisols and Cambisols have been formed. The associated shales have acidic soil association of Dystric Cambisols, Umbrisols and Alisols, while the eroded sandstones have Arenosols, Umbrisols or acidic Luvisols with some podsolization.

The soils of the rhyolite and andesite rocks and their tuffs of the North Hungarian Range – Börzsöny, Mátra and the Tokaj (Zemplén) Mountains – are also acidic, especially on higher elevations, where the pH can drop to 4 and even podsolization can be identified. The basalt region is limited to the Medves Region with Leptosols and Phaeozems.

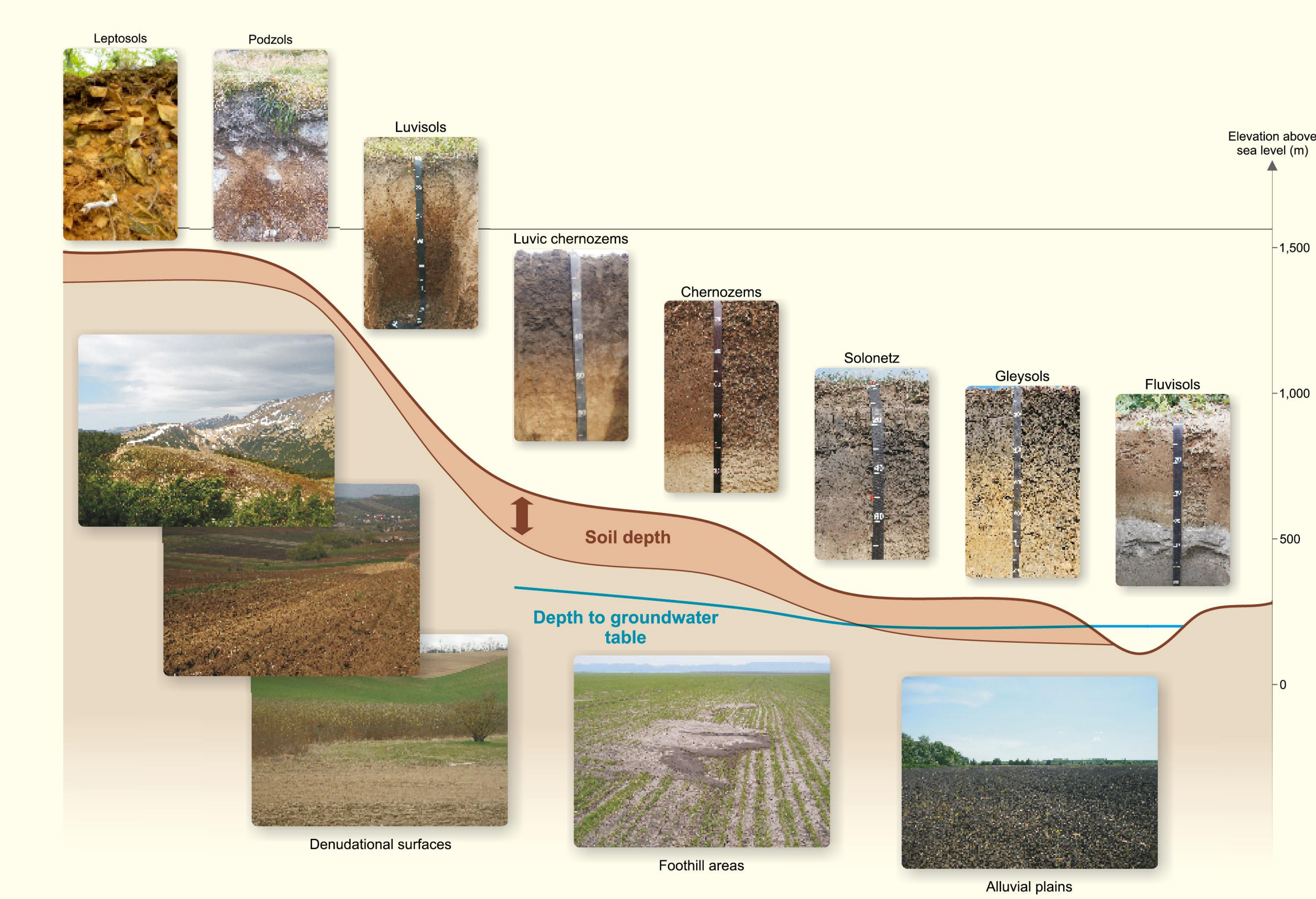
The foothill areas have a lot of mixed in loess material, therefore acidity decreases significantly thus the A-horizon become deeper and typically brown forest soils (Luvisols) are formed.

The Nógrád (Novohrad)–Abaúj (Abov) Depression is built up by the unconsolidated Oligocene–Miocene sand and clay layers and the loess on them. They are characterized by Luvisols, but Regosols on the ridge tops and very deep Phaeozems or Gleysols in the valley bottoms are also common.

The ranges of the Northeastern Carpathians are more uniform, mainly sandstones of the flysch zone and the andesitic ranges of the inner volcanic arch. The flysch zone is characterized by acidic, sandy soil types, like shallow Umbrisols and less developed Cambisols, Acrisols and Podzols on the stable surfaces, while the volcanic ranges have finer textured Umbrisols, Cambisols and Luvisols.

The Eastern Carpathians has similar soil associations. The ranges are higher, so there is more precipitation, stronger leaching and acidification. The dominating parent materials are volcanic andesite, metamorphic schist, shale and sandstone on the eastern side. Podzols are most common on the higher altitudes. Descending from the Podzols region, Alisols and Acrisols become the most common soils together with Dystric Cambisols. The unique soil feature of the area is Andosol, especially on the younger volcanic rocks of the inner volcanic zone. The basins lying among the higher mountain ranges, have strong hydromorphic impact on the soil formations, therefore Gleysols and Stagnosols are the most common soil types on the

6 TYPICAL SOIL TOP SEQUENCE OF THE CARPATHIAN BASIN



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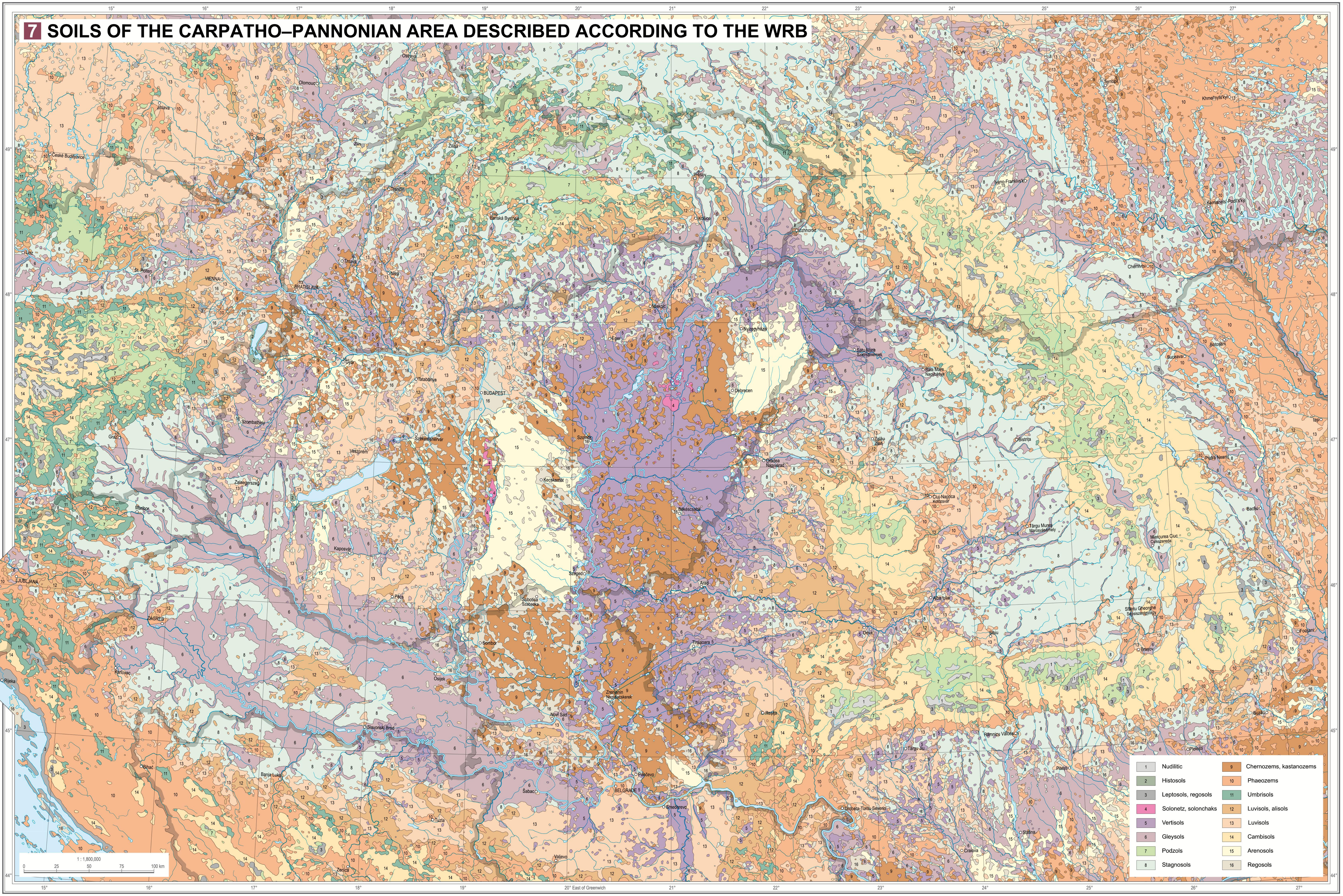
7 SOILS OF THE CARPATHO–PANNONIAN AREA DESCRIBED ACCORDING TO THE WRB



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clayey colluvial material. The foothills of the western ranges have some rock-salt close to the surface. These areas have saline soils, mainly in the valley bottoms where significant amount of dissolved salt can accumulate in the saturated soils. Salt effect can be identified on the steeper slopes as well, where erosion is very strong and fresh salt gets close to the soil surface.

The bare rock surfaces of the Southern Carpathians occupy large areas of the crystalline gneiss and granite. The lower altitudes with deeper soils have Dystric Leptosols, Umbrisols and Podzols. The outcropping limestone area has Rendzic Leptosols on the erosion surfaces and Cambisol – Luvisol associations on the slopes with deeper strata of the colluvic materials.

The crystalline rocks part of the Apuşeni Mountains, composed of granite, gneiss and shale are occupied by Podzols, Cambisols and Umbrisols. The acidic eluvium of the shales supports the formation of Dystric Cambisols, while the limestone derived soils are much less acidic and they are mainly Rendzic Leptosols or Eutric Cambisols. The lower lying sandstone regions also have acidic, light textured forest soils, mainly Alisols and Cambisols, with slightly expressed podsolization processes. The neutral and basic volcanic rocks are covered by loamy-clayey Luvisols.

The dominant parent material at the Silvana (Szilágyság) Hills and the neighbouring Transylvanian Basin is loess, which support Chernozems development. Leaching increases eastwards due to increased precipitation levels and shallower loess cap over the Tertiary sea sediments. Thus, the soils are changing accordingly; Chernozems are replaced with Phaeozems, Cambisols and Luvisols. Regosols and Vertisols diversify the soil resources on the varying clayey and sandy sea sediment layers of the basin. The clay sediment layers are more common, due to its higher resistance to erosion. Luvisols and Alisols are the most common soil, but Stagnosols can be found as well on the near level surfaces. Clayey layers might have been cut through by erosion and sandy layers have been exposed, which erode faster and develop steep slopes with sandy, loamy sandy or loamy Regosols. Clay bands may limit the infiltration, so the soils above can get saturated and heavy and may start moving downwards as landslides or as soil creeping. The valley bottoms of the undulating surfaces accumulate a lot of humus rich soil material from the neighbouring slopes and deep Phaeozems, Humic Regosols or – in case of hydromorphic impacts – Gleysols or Gleyic Phaeozems can be developed.

The mountains bordering the Carpathian Basin from the South are composed mainly of limestone and dolomite with associated sandstone and shale strata. The higher ridges of limestone areas are covered by Rendzic Leptosols and very shallow Luvisols with eroded bare surfaces in turn. These soils are reddish colour soils with neutral or slightly acidic pH, low organic matter content and low water holding capacity. Therefore these areas are very much exposed to drought risk. The depressions with deeper sediments can collect colluvic materials of several meter depth. The sandstone and shale areas have much deeper soils, mainly Cambisols and Luvisols, which are the only productive soils of the regions. The reddish Luvisol (Chromic) with shallower A-horizon and significant amount of iron-oxide to colour the material are the so-called 'terra rossa', which is the most well-known soil of the region.

The area between as well as south of Tuzla and Banja Luka is characterized by gabbro. The soils are very clayey Umbrisols, slightly acidic Cambisols, Stagnosols and Stagnic Luvisols. The accumulation areas of the smaller basins have Vertisols, with high amount of swelling clay.

The plains, hills and mountains of the Pannonian Basin represent a very different soil forming environment and soil associations. The Pannonian Basin is bordered from the west by the eastern most extensions of the Eastern Alps. The ridges of these mountains are composed mainly of carbonate rocks with Rendzic Leptosols, like in the Northern Limestone Alps, or of very old metamorphic rocks, like gneiss, phyllite or mica, with acidic, sometimes Spodic, Albic Cambisols and Luvisols.

The only area of the Pannonian Basin having higher relief and relatively higher altitudes – up to 600–700 m above the sea – is the Transdanubian Range, where Cambisols and Luvisols are the most dominant soils. The higher and more dissected ranges with stronger erosion have Leptosols – mainly Rendzic Leptosols and deeper Luvisols on the dominating carbonate rocks. The soils of the basalt areas are black, shallow, humus-rich Leptosols with often high amount of clay. Moreover, Vertisols and Phaeozems are also common. The Tertiary sediments of the basins among the mountain ranges support the formation of Luvisols, while the foothill areas with loess enriched parent material have less leached Cambisols. Also, small spots of Histosols exist as well in the lower lying depressions.

The climate – and the soils as well – of the interior part of the Pannonian Basin is characterized by a western–eastern transition. The Western part of the region belongs to Luvisol zone, while the Eastern plains are more continental and Chernozem is the zonal type.

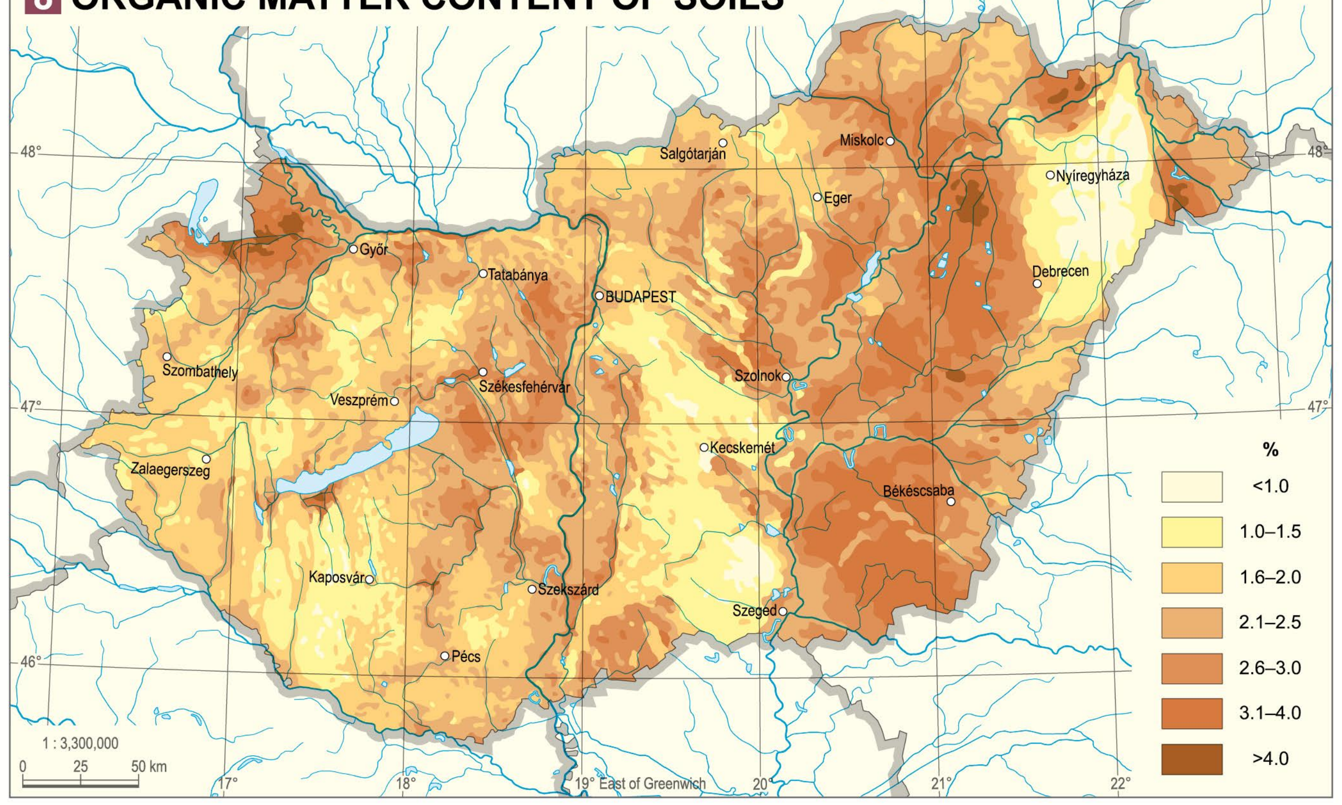
The most humid southwestern part of the Basin (Alpokalja/Eastern Alpine Foreland, Dráva–Sava Region/Southwestern Pannonia) has both the Sub-Mediterranean and the Atlantic climates contributing to the higher humidity. The strongly weathered parent material has higher clay content. Clay illuviation process is very strong, so the clay content difference between the eluviation and accumulation horizons can increase high enough to limit the water infiltration and develop Stagnic properties that make these soils difficult to cultivate. Earthing up is a common growing practice to handle this problem.

Due to the low infiltration and the high precipitation, the depressions and the valley bottoms can accumulate enough water to saturate the soils and support peat formations. These Histosols used to be common before draining them.

The majority of the Transdanubian Hills are covered by a loess blanket, and can be characterized by a climate driven western–eastern transition of Luvisols, Cambisols, Humic Cambisols and Chernozems – when leaving the area toward the Mezőföld. The most common texture class of the forest soil zone is clay-loam, but the texture is changing accordingly. The Cambisols are mainly loams, while the Chernozems are loams and sandy loams. The spatial variability of the soil types is defined by the topography driven soil material redistribution processes of erosion and re-sedimentation accelerated by the intensive agriculture. The wide flat interfluves have uneroded soils, while the strongly eroded shoulders and the back-slope areas may lose their complete soil profile exposing the calcareous parent material to the surface such as Calcaric Regosols or Calcisols – when the carbonate accumulation zone is exposed. The foot-slope and valley bottom areas accumulate the eroded surface materials and deep, Humic, Colluvic profiles are developed with occasional hydromorphic impacts in the deeper part of the solum. The acidic sand region of Inner Somogy has Cambisol, Arenic, Cutanic Luvisols and Lamellic Arenosols.

The loess covered older terraces and the edges of the Kisalföld (Little Hungaian Plain) have Chernozems and Phaeozems, occasionally with Gleyic properties in the deeper horizons. Cambisols are on the foothill areas toward the neighbouring regions. The textures of these soils are mainly loam, sandy loam, with neutral pH and high productivity. The only potential limitation of its productivity is the sandy, gravelly alluvial sediment under the loess strata that cannot lift the groundwater up to the finer textured soils of the root zone. The water supply is limited to precipitation only, which makes the area exposed to higher drought risk. These soils may also have thin, but petrified secondary carbonate accumulation – petrocalcic horizons – which can limit the root penetration and the access to the groundwater.

The Fertő–Hanság region is a unique area with drained Histosols and Gleysols and some salt-effected soils. It is – and also the Rábaköz, south of it – a big depression with alluvial clay and clay-loam parent material. The eastern part (Hanság) used to be a peatland. The area has been drained and only small remnants of the peat country have remained. The Fluvic material dominated Fertő (Neusiedler See) Region has mainly Chernozems; salt effected soils in small extents occur as well – Sulphatic, Mollic Solonetz and Solonchak soils. These are the westernmost occurrence of salt effected soils in the Carpathian Basin.



8 ORGANIC MATTER CONTENT OF SOILS

The Fluvisols of the Žitný ostrov (Csallóköz) and Szigetköz are having sandy, gravelly fluvial parent material with finer sandy loam texture on the top.

The other important and unique feature of the Kisalföld, especially the Southern part of it, is the gravelly material on the surface. The texture is sandy loam – loamy sand with high amount of gravel. The weatherable part of this acidic and coarse material is not much, but the clay that has been formed as secondary silicate is quite visible as strong clay coatings, binding material on the gravel surfaces. The most common soil types are Cutanic Luvisols and Alisols with often high enough gravel content to meet the Skeletic criterion. These soils have low productivity and are mainly under forest cover.

The Eastern part of the Alföld (Great Hungarian Plain) – east from the Danube – can be divided into several unique soil forming regions defined by the different parent materials and by the depth to groundwater. The currently sinking areas, like Kis-Sárrét, Nagy-Sárrét, Bodrogköz, Rétköz, Bereg–Szatmár Plain, had been wetlands up to 150–200 years ago, but the majority of their area has already been drained. The peat has been oxidized and decomposed, or burnt and has been replaced by Gleysols. The channel system of the Tisza and its tributaries is surrounded by recent alluvial sediments. Areas directly along the river have coarser sandy, sandy loam sediments, while the material of the alluvial plains behind the natural levees is heavy textured clay or clay loam. These separated depressions used to have logging water for weeks or months after floods and very fine clayey material was sedimented. These areas have low depth to groundwater, so the most common soils are the Gleysols and Vertisols with associated Solonetzes. These soils are often very acidic, unless there is much carbonate rich loess mixed into the alluvial material.

Real Fluvisols are only occurring within the artificial dikes along the rivers. The natural floodplains have been freed from the annual floods since the second half of the 19th century. The Fluvic properties had been complemented by strong humification and Mollic-horizon development and or in several sites by sodification or salinization which resulted in the formation of secondary salt effected soils, like mollic Solonetzes and Solonchaks. Fluvisols shown on the legacy maps do not exist anymore, they lack the requirements of the annual flooding. The eastern floodplain of the Danube is characterized by carbonated alluvium and has Chernozems with Gleyic and Fuvic properties and also some Solonchaks close to the edges of floodplain. Both soils have sandy loam, sandy textures.

There are several regions on the plain being tectonically uplifted. These areas are either covered by loess – the so-called loess plateaus – or by sand forming sandy hills. The loess areas with Chernozems soils – like the Hajdúság, Körös–Maros Midland, Bácska Plain, and Banat Plain – are among the most important agricultural areas.

The Danube–Tisza Midland Ridge is built up from the Danube sediments, worked out, classified and redistributed by the wind. The parent material of these sandy dunes is calcareous sand with often more than 15% calcium-carbonate. There are only a few exceptions in the Northern part of the region, where northwest – southeast oriented elongated loess plateaus with Chernozems diversify the landscape. The dunes have Arenosols and sometimes Calcisols with shallow A-horizons, while the depression, valley bottoms between the dunes has sandy Gleysols and Solonchaks in smaller spots.

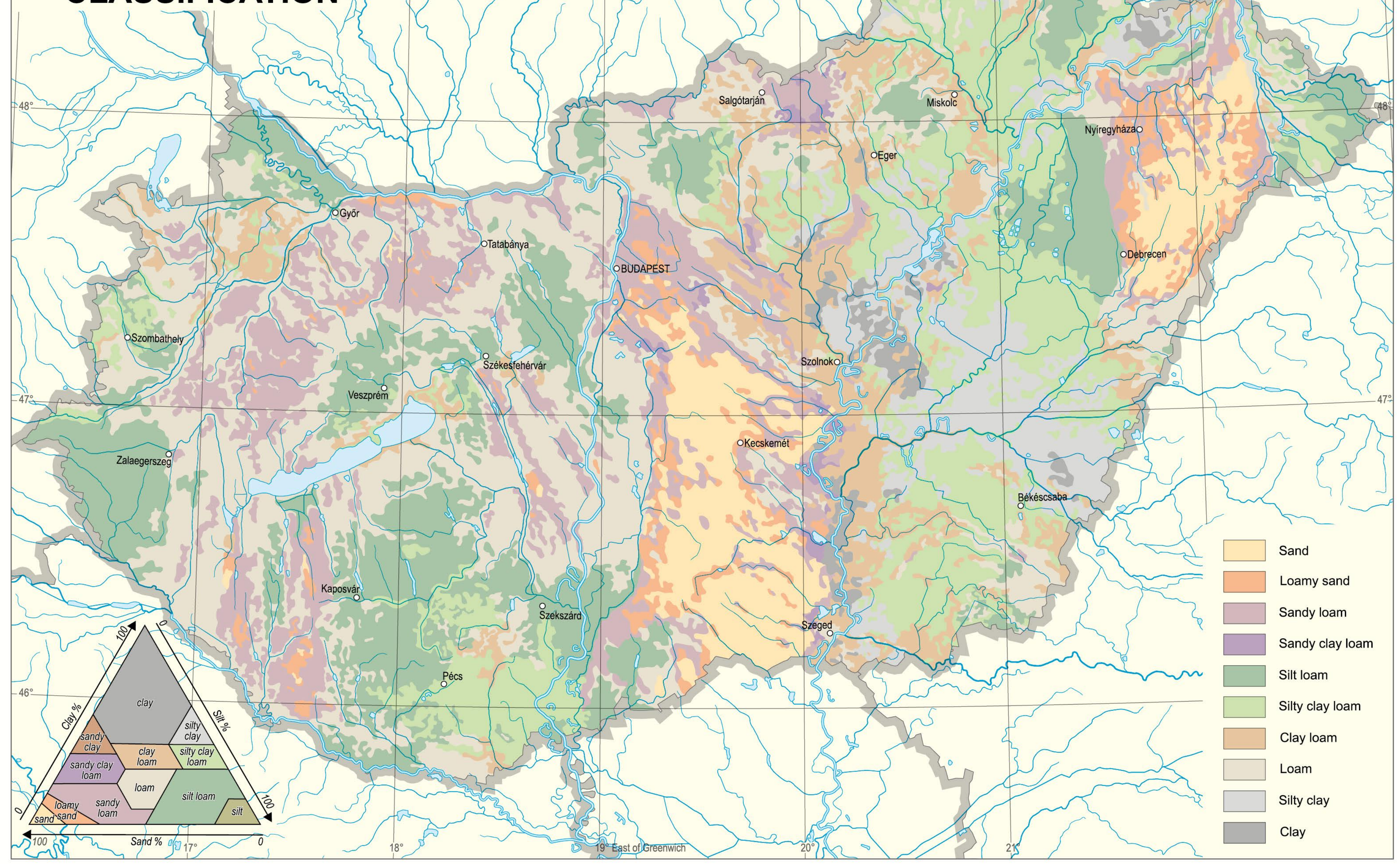
The other major sand region is the Nyírség, where the sand is acidic and Lamellic Arenosols are the most important soils types of the elevated dunes.

The main environmental and economic characteristics of soils

Soil quality is important from environmental and economic aspects. It is determined by the soil's physical, chemical and biological properties, and their consequence, soil state. The soil cover of the Carpathian Basin, including Hungary, shows high spatial and temporal variability. In the present chapter, three of the basic soil properties and two of the soil functions are illustrated in the map form.

Organic matter reserved in soil is of vital importance not only for soil science and agriculture, but for environment protection as well. The spatial distribution of soil types is well reflected by the organic matter content of Hungarian soils 8. Soils having the highest (>10%) organic matter content are found in the country's boggy regions (in the basin of the Kis-Balaton, in the Hanság, Nagyberek, Ecsed Swamp, Kis- and Nagy-Sárrét regions), where the mineralization of organic matter is inhibited by permanent or periodical waterlogging. Areas mainly covered by chernozem soils (such as the Mezőföld, Körös–Maros Midland, Hajdúság regions) are rich in organic matter, which is the result of soil formation under the primary natural grassy plant cover. Blown sands and humous

9 MECHANICAL COMPOSITION OF THE TOP SOIL LAYER ACCORDING TO THE USDA TEXTURE CLASSIFICATION



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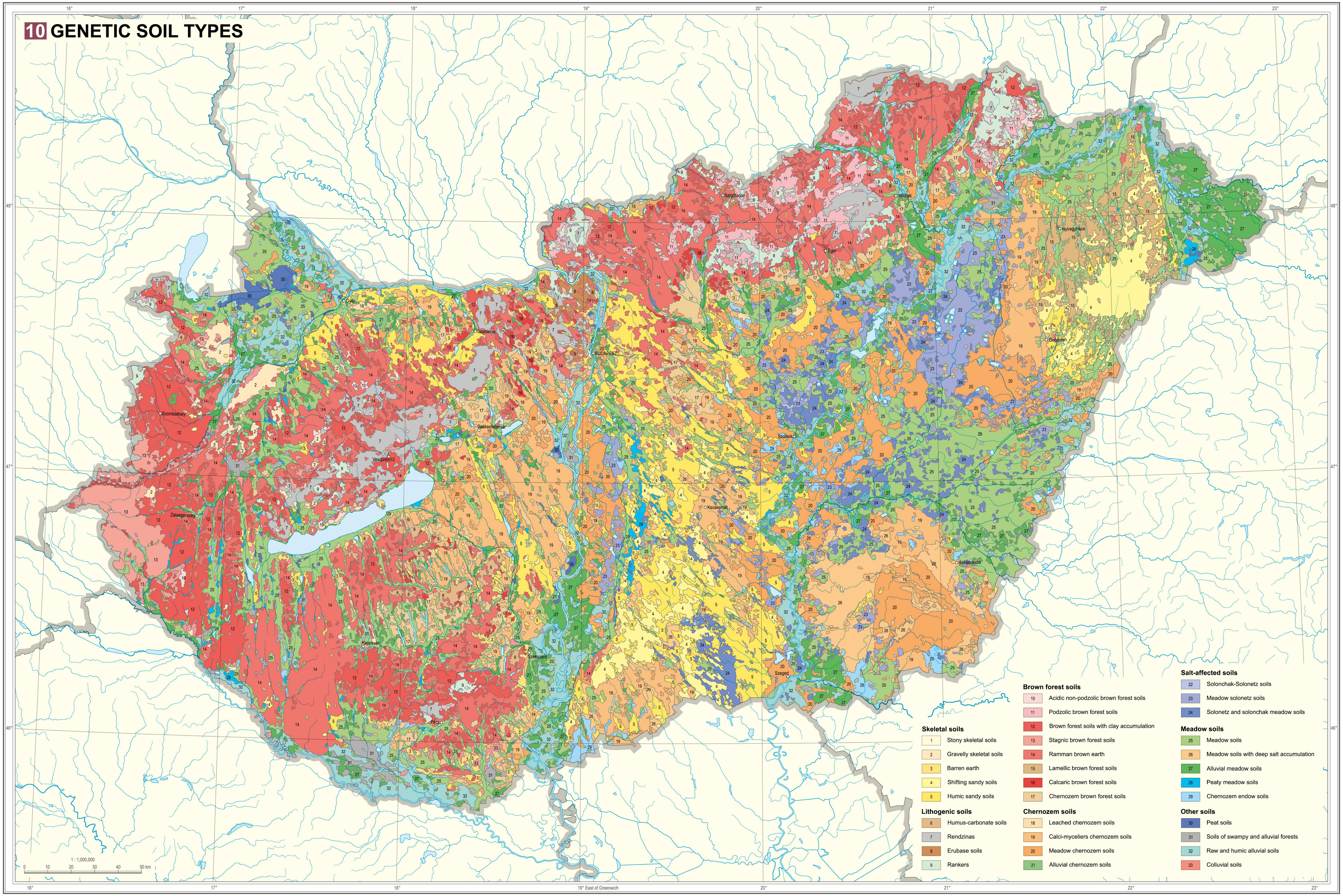
10 GENETIC SOIL TYPES



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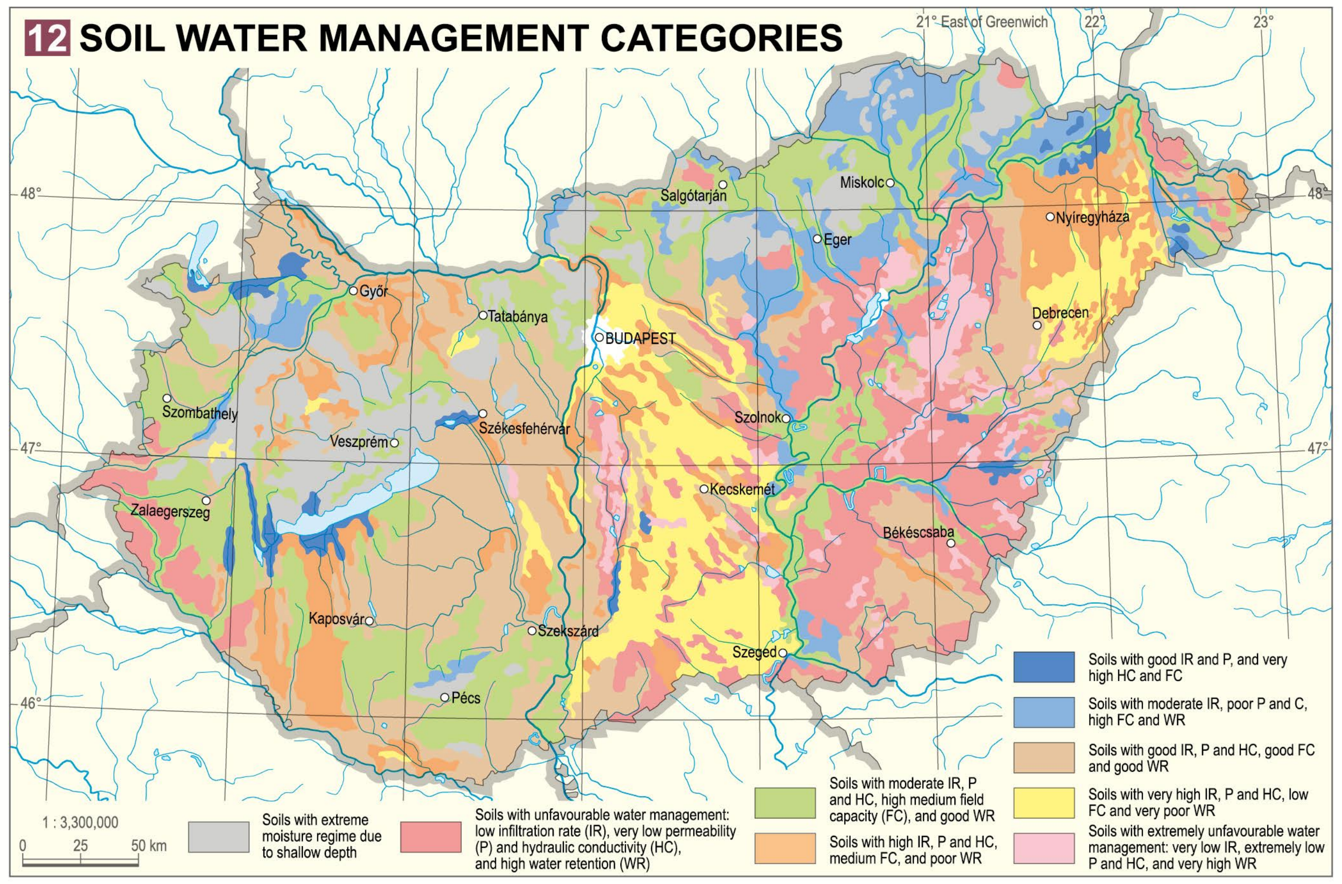
sandy soils (which occur considerably in the Danube–Tisza Midland Ridge, or the Nyírség regions) typically have low organic matter content. Soils covering medium-height mountain ranges having limestone or dolomite parent rock are very rich in organic matter. Rendzinas formed on these areas may have an unexpectedly high organic matter content, although their tilth layer is often shallow (<30 cm) and stony, and the water quantity stored in the profile is very low.

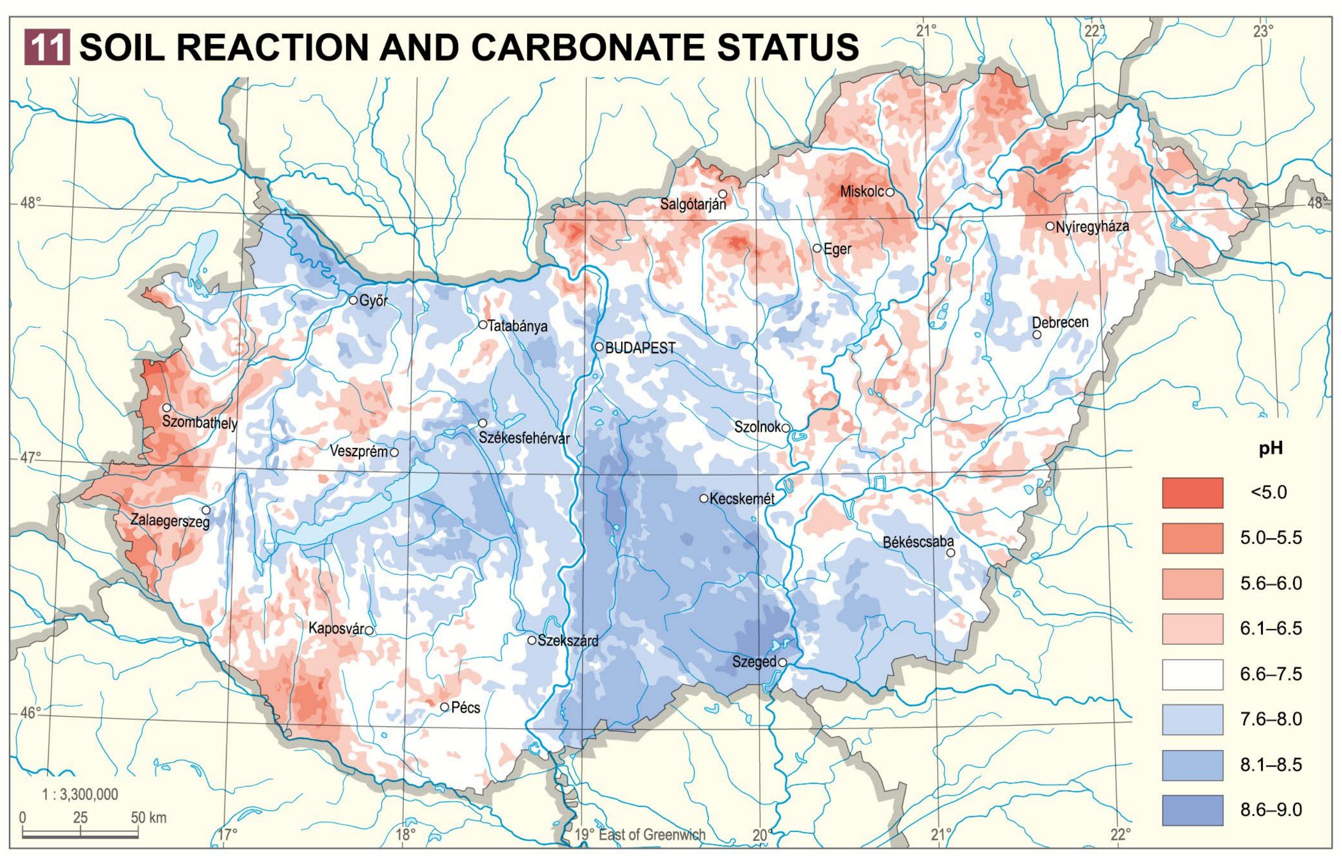
Soils can be described by different physical properties, from which soil mechanical composition (soil texture) is the most informative. Soil texture influences other physical (hydro-physical, erodibility), chemical and biological soil properties. According to the proportions of clay, silt and sand to each other, different soil texture classes were classified, which are illustrated by the division of the texture triangle 9. The twelve-class system used by the United States Department of Agriculture (USDA) is the internationally most wide-spread classification for soil texture. Its categories and the distribution of physical characteristics of Hungarian soils according to the USDA system are shown on Map 9. The spatial distribution of soil texture classes reflects the characteristics of Hungarian regions. Large extended sandy areas can be found in the Danube–Tisza Midland Ridge and Nyírség regions 10. Other areas of the Alföld are covered by soils with heavier texture, such as silty loam, silty clay loam, clay loam and sandy loam. The heaviest silty clay and clay soils also occur on the Alföld, along and surrounded by the rivers Tisza, Körös and Hortobágy–Berettyó. Silty loam and loam soils are found on extended areas in the North Hungarian and Transdanubian Ranges. Soils with silty loam, sandy loam and loam texture are dominant in the Transdanubian Hills.

The map of soil reaction and carbonate status of Hungarian soils 11 distinctly shows the calcareous humous sandy soils of the Danube–Tisza Midland Ridge, and the salt affected soils (which are alkaline) also found in this region and on other areas of the Alföld. Soils formed on loess of the Körös–Maros Midland, Mezőföld and Kisalföld regions are slightly alkaline because of their carbonate content. Sandy soils of the Nyírség and the clayey meadow soils of the Alföld are acidic. Acidic soils have developed on large areas in the Western parts of the country, in the Transdanubian Hills and North Hungarian Range. Soil pH of the Transdanubian Range – in accordance with other soil attributes – shows great variability.

Soil is potentially the largest natural water reservoir of Hungary; its 0–100 cm of the upper soil layer hypothetically may store more than half of the average annual precipitation simultaneously. This favourable fact is quite contrary with the high and increasing frequency and duration of extreme hydrological events occurring in the Basin (and especially on its fertile plains). The reason of this contradiction is that the huge potential water storage capacity of soil is limited, the result of which is characterized by the hydro-physical properties of soils 12. Such limitations are: infiltration of water into the soil is prevented (i.e. the pore space is filled up by a previous source of water, the topsoil is frozen, the soil has a nearly impermeable layer on, or near to its surface), or the infiltrated water is not stored, it percolates through the soil profile and is unavailable for plants (the reason for which is poor water retention, infiltration losses or high wilting percentage). The key issue of agricultural water management is to help the efficient use of the potential water storage capacity of soil. Forty-three percent of Hungarian soils are characterized as unfavourable, twenty-six percent as moderately favourable and only thirty-one percent as favourable moisture regime. The reasons of unfavourable moisture regime are: extremely high sand content (coarse texture) in the Danube–Tisza Midland and Nyírség regions, high clay content (heavy texture) along the Tisza River, salinity (in the Alföld), waterlogging and marsh formation (in low-lying and waterlogged areas) or shallow depth (mainly in mountainous and hilly areas). Moderately favourable moisture regime is due to light texture (in the Northern Nyírség and Inner Somogy regions), clay accumulation in the soil profile (on forest areas) or salinity in the deeper layers (in the Southern Alföld region).



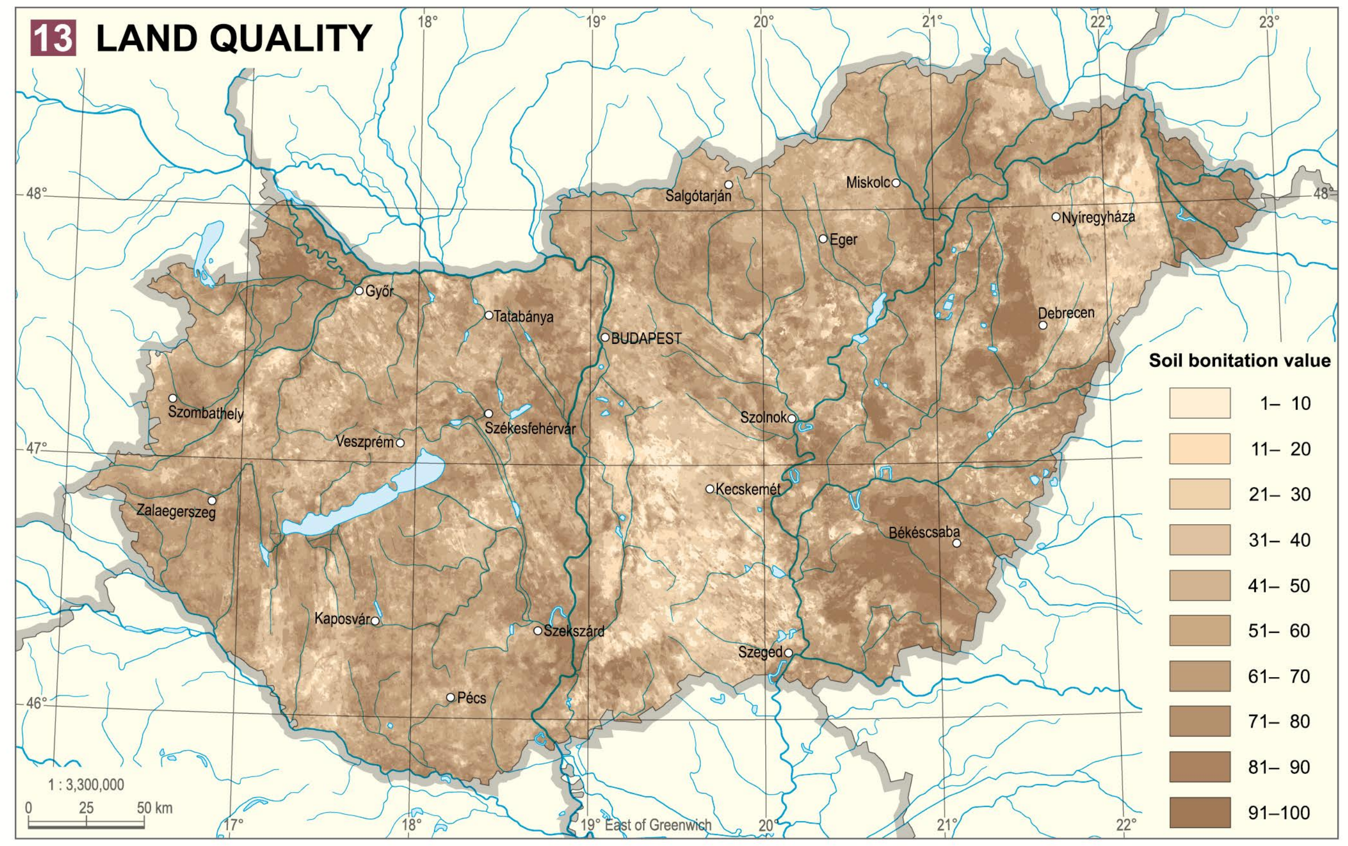
12 SOIL WATER MANAGEMENT CATEGORIES



11 SOIL REACTION AND CARBONATE STATUS

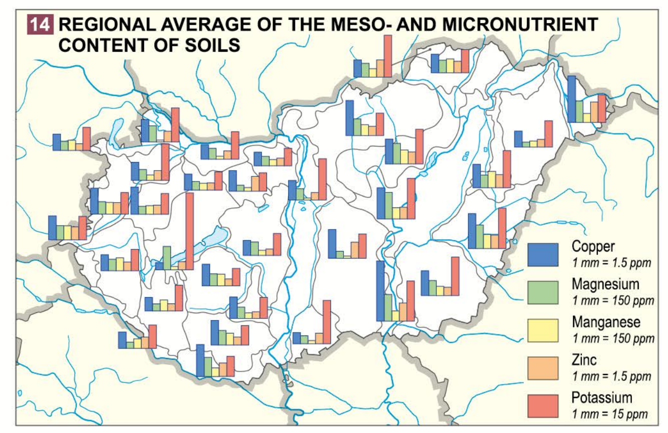
The most important and specific characteristic of soil is *fertility,* the special ability that water, air and available plant nutrients occurring in soil may cover – to a certain extent – the main requirements of the natural vegetation and cultivated crops. Soil fertility is a plant-specific property, which should be used with the possible harmonization of land site requirements and natural conditions and with the consistent enforcement of the 'grow each plant where it belongs' principle. The *land quality index*, expresses the potential of a given land site. It is a dimensionless relative number derived from the soil productivity value (showing the rate of soil fertility/productivity) and from climatic and relief factors. It shows the fertility/productivity of soils on a uniform scale from the least one (1) to the most fertile/productive (100). The territorial distribution of the index 13 underlines that there are significant differences in the characteristic land quality of Hungary's main regions and soil fertility is diversified within the regions themselves. Among the main regions of Hungary, the Alföld has the outstandingly best plant production potential due to its large aerial extension and the high ratio of soils with good fertility (mainly located in the Tiszántúl region). In the Danube–Tisza Midland soils with low and moderate quality are dominant. In the Transdanubian Hills there are great differences between the soil fertility of certain micro-regions, areas with poor, moderate and favourable conditions – with the exception of the Mezőföld region – occur in mosaic-like variability. Among Hungary's main regions, the Kisalföld is the most fertile/productive, which is followed by the Alföld and Transdanubian Hills having variable soil fertility, the Eastern Alpine Foreland which has much lower fertility, the North Hungarian Range and the Transdanubian Range with generally the most unfavourable landsite conditions.

Traditionally agriculture is the most significant user of soils. The agricultural evaluation of soil state is done on the basis of fertility/productivity. From the viewpoint of plant production favourable soil state occurs



13 LAND QUALITY

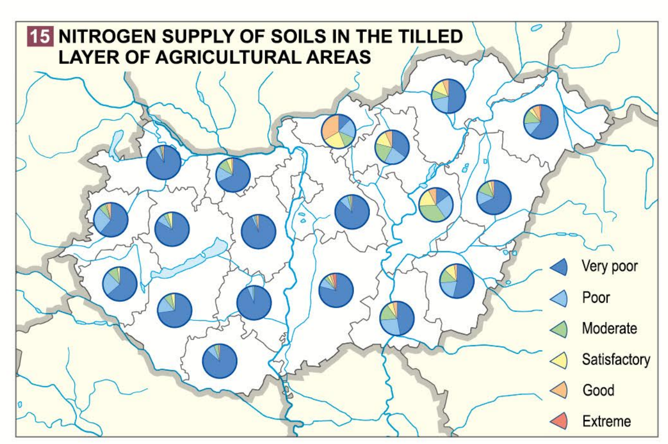
when the moisture, air, heat and nutrient regimes of soil are in accordance with plant requirements. The risk and costs of plant production decrease the safety and efficiency of food production, increase on soils with favourable physical, chemical and biological conditions. During the evaluation of soil state, in addition to plant production requirements, the aspects of other soil functions and their influence on the environment should also be taken into consideration. The effect of agricultural land use manifests rapid changes in qualitative and quantitative soil parameters as compared to natural processes. Due to these facts, information related to farming is of primary importance for the characterization of the soil cover of agricultural areas. The Soil Degradation Information Subsystem of the National Environmental Information System includes data related to agriculture-induced environmental stresses, the environmental state of soils, originating from load data collection and soil state assessment carried out on selected typical farms representative for the whole country. Some of these results are presented on county-level maps.



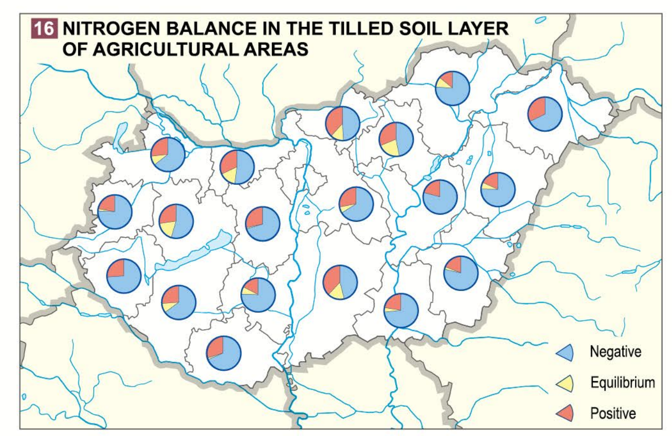
14 REGIONAL AVERAGE OF THE MESO- AND MICRONUTRIENT CONTENT OF SOILS

A thorough knowledge of all physical and chemical parameters of soil is necessary for the implementation of a consistent nutrient management technology. Among its nutrient supplying properties not only nitrogen (N), phosphorus (P) and potassium (K) contents of soil should be known on the long range, but its meso- or microelement contents – such as, soluble copper (Cu), magnesium (Mg), manganese (Mn), zinc (Zn) and sodium (Na) 14. These elements are required only in small amounts by plants, but are essential from the point of view of their role in the plants' vital processes, therefore their deficiency leads to decline in yield quantity and quality. The map shows the influence of different geological conditions on the microelement content of soils. It can clearly be seen that Cu, Zn and Mn concentrations are higher in the Tisza's catchment area. The reason of this is the frequent occurrence of rocks rich in ore on the source areas. This natural phenomenon was intensified by the mining of metal ore for centuries in the mountainous areas, where the debris of the spoil banks was washed into the water of the rivers during heavy rains. The measured values are low in absolute sense; they are below the limit values, which confirm that soils are clean and free of pollutants.

Nitrogen is the macro-element taken up by plants in the largest quantity, so it is one of the most significant nutrient elements in the agricultural nutrient replenishment technology. The nutrient supply category – determined on the basis of the soil type, texture and humus content – gives information on the amount of plant available nitrogen, or makes it possible to establish the extent to which the applied plant production technology has been adjusted to the plant's actual nutrient demand 15. Based on the nitrogen supply level of the plough layer (0–30 cm) the given plant culture's nutrient management approach – that is the quantity of organic and mineral fertilizer required to reach the expected yield level on a given soil – can be planned.



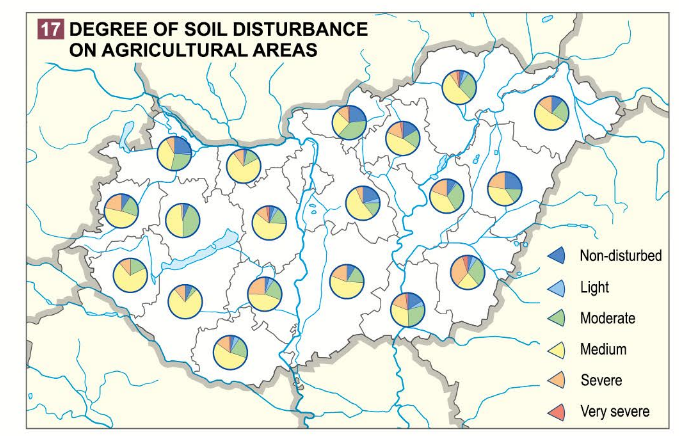
15 NITROGEN SUPPLY OF SOILS IN THE TILLED LAYER OF AGRICULTURAL AREAS



16 NITROGEN BALANCE IN THE TILLED SOIL LAYER OF AGRICULTURAL AREAS

The nitrogen balance of the studied agricultural fields 16 was calculated using a simplified model, where the nitrogen amount was added to the soil by fertilization on the one hand and on the other hand, the nitrogen quantity withdrawn from the soil by the produced crop yields were taken into account. On the basis of the map showing the balance between nitrogen input (fertilizer) and nitrogen output (crop uptake), it can be established that two thirds or three fourths of the arable land have a negative balance, meaning that the nutrient amount taken up by plants is higher than the input amount. The difference can be explained partly by the atmospheric precipitation of nitrogen compounds, and by the natural nitrogen supplying capacity of soil. The nitrogen balance is highly year dependent; in drought years, plants are not able to take up the distributed nutrients, so at the end of the vegetation period they partly remain in the soil, resulting in a positive nutrient balance. The map compiled on the basis of county data indicates that in counties with light-textured soils, lower amounts of precipitation, that are more drought-sensitive (Bács-Kiskun, Szabolcs-Szatmár-Bereg) resulted in larger quantities of nitrate remaining in the soil.

Interpreting both nitrogen supply and nitrogen balance data, it can be seen that in counties whereby the nitrogen balance shows a higher surplus, the soils contain more nitrate at the end of the vegetation period. The fate of this nitrate depends on the winter season weather; in case of high precipitation, amounts to part of the measured quantity is leached into the deeper layers, which causes nutrient losses for agriculture, and pollution risk from a water protection point of view. All the same, the distribution of rates is not unfavourable, extreme supply represents a low proportion in the counties, and the related environmental risk is not considered to be high.



17 DEGREE OF SOIL DISTURBANCE ON AGRICULTURAL AREAS

The degree of soil disturbance 17 is determined by the analysis of soil cultivation procedures. In the course of collecting management data, equipment/machinery and depth of base soil tillage were studied on the agricultural fields drawn into the investigation. The data of 2011 are shown on the map. The rate of soil disturbance was categorized on the basis of the mechanical stress caused by the tillage equipment. Large-scale crop production – usually accompanied by multiple cultivation operations – occurs in the most intensive production regions (Békés, Fejér, Komárom-Esztergom Counties). The direct deteriorating effects of improper agrotechnics on soil are structure destruction, and oxidation of organic matter. Its indirect influence is similarly important, which exerts its negative effect by increasing soil erosion and decreasing soil biological activity.

On intensively used agricultural land – especially due to improper soil use and agrotechnics – soil deterioration (soil degradation) may occur. The deterioration of soil conditions due to anthropogenic effects are discussed in detail in the *Environment protection* 27–31 chapter, while *Natural hazards* 20 chapter discusses soil erosion resulting from the influence of natural processes.

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