SOIL, AS A MULTIFUNCTIONAL NATURAL RESOURCE

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Abstract: Soils represent a considerable part of the conditionally renewable natural resources. Consequently, rational land use and proper soil management are important elements of sustainability and have special significance in the national economy, environment protection, and even in rural development. The main soil functions are as follows:

- reactor, transformer and integrator of the combined influences of other natural resources;
- medium for biomass production, primary food-source of the biosphere;
- storage of heat, water, plant nutrients and wastes;
- high capacity buffer medium, which may prevent or moderate the unfavourable consequences of various stresses;
- natural filter and detoxication system;
- significant gene reservoir, an important element of biodiversity;
- conservator of natural and human heritages;
- basis for constructions.

Society has utilized these functions in different ways (rate, method, efficiency) throughout history, depending on the given natural conditions and socio-economic circumstances. In many cases irrational (misguided) management leads to "soil loss", functional disturbances and environment deterioration. The prevention or reduction of these unfavourable consequences requires permanent care and efficient control of soil processes.

Keywords: soil functions, soil fertility, resilience, soil degradation, control of soil processes

2015 is the "International Year of Soils". This paper was compiled for and is dedicated to this event.

Introduction

Each society wishes and tries to create favourable living conditions for its members. **"Life quality criteria"** are formulated in different ways by various societies or individuals, depending on the given geographical and socio-economic conditions, living standards; national, ethnical and religious traditions; history, policy; age, sex, educational level, position in the social hierarchy; etc. However, there is full agreement in three elements:

- sufficient quantity of healthy, high quality food: food security;
- clean water;
- pleasant environment.

All three are closely related to the **rational use and proper management of natural resources**. The relationships and interactions between resources and the requirements of society are schematically illustrated by Figure 1. (Lal, 2002; Várallyay, 2010a).

Sustainability and soil resources

Sustainability is a general concept: the management (use and conservation) of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and *continued satisfaction of human needs for present and future generations.* In agriculture the use of efficient, environment-friendly, non-degrading, energy- and material-saving technologies, which are technically appropriate, economically viable and socially acceptable (Greenland and Szabolcs, 1993, Láng et al., 1983, Várallyay, 2003).

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Figure 1. Relationships between resources and the society

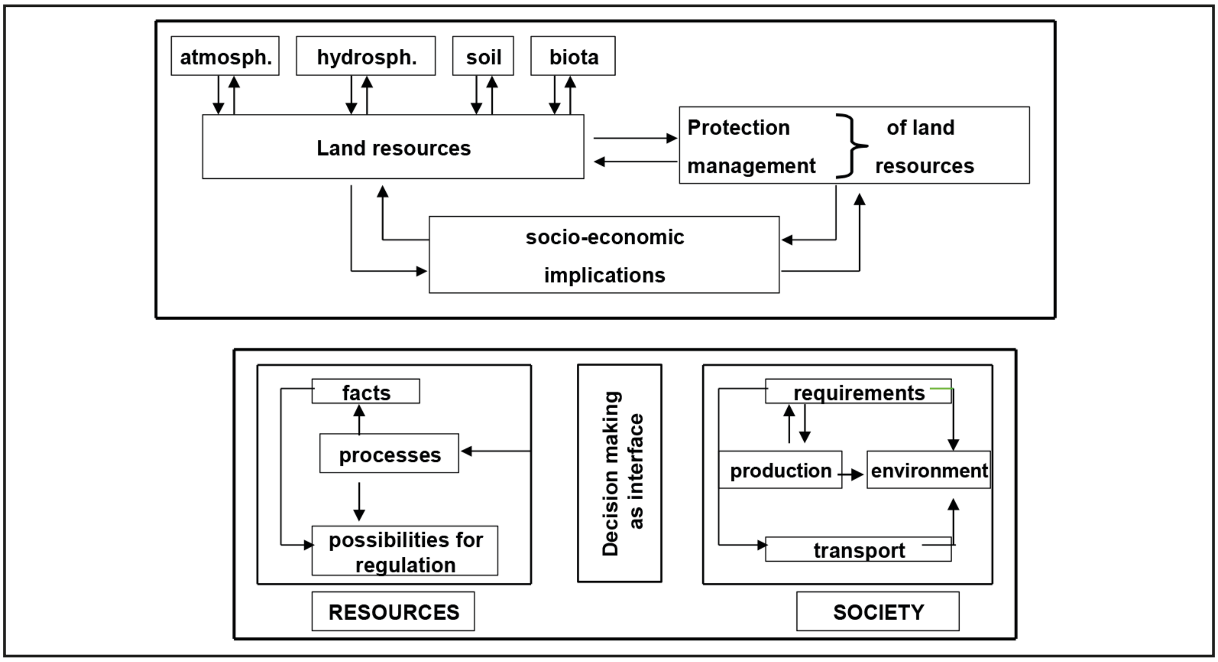
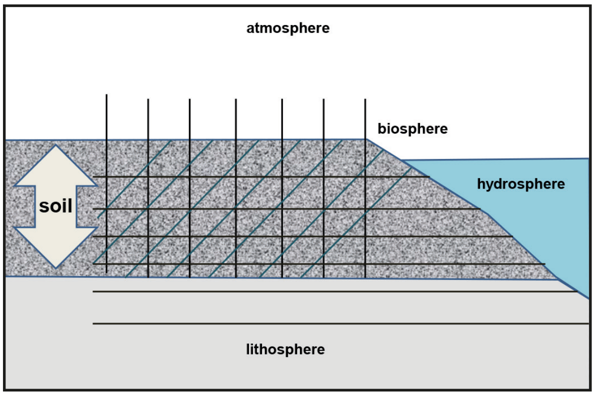


Figure 2. Soil formation by spheric interactions



Soil formed in the interaction zone of the lithosphere, atmosphere, hydrosphere and biosphere (Figure 2) (Németh et al., 2005, Várallyay, 2010a). Soil has three specific/unique characteristics (Greenland and Szabolcs, 1993, Németh et al., 2005, Lal, 2002, Várallyay, 1997, 2003, 2010a):

(1) Conditionally renewable natural resource.

As a consequence of their rational use they do not change *irreversibly,* they do not disappear, their quantity and quality doesn't decrease unavoidably, totally and fundamentally. But their potential renewal – based on their *resilience* – doesn't occur automatically and requires permanent quality maintenance and conservation activities: rational land use and cropping pattern, proper agrotechnics, and – in some cases – remediation, reclamation or amelioration.

(2) Resilience.

Resilience is „quality or property of (quickly) recovering the original shape and conditions after being stressed (pulled, pressed, crushed, etc.)".

Soil resilience is a specific ability that soil may recover (renew) from various disturbances, natural or human-induced **stresses**. Soil resilience is not a general property of soil. It depends on the soil properties and soil processes, as well as on the character and intensity of the „disturbance", **stress,** which determine the rate of recovery after „stress-stop" and formulate the tasks to help this **renewal.**

(3) Multifunctionality.

Because of these unique characteristics soil is a key factor of sustainability, the possibility and quality of life and social development. The driving forces, spatial and time dimensions of these characteristics are summarized in Figure 3 (Soil Atlas of Europe, 2005).

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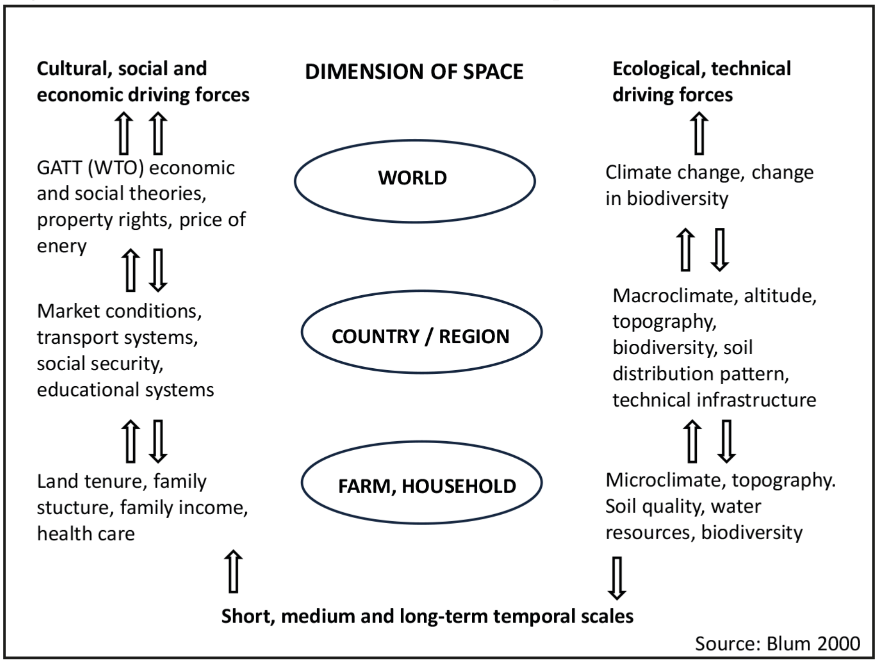
Figure 3. Land and soil assessment dimensions in space and time (Bloom 2000)



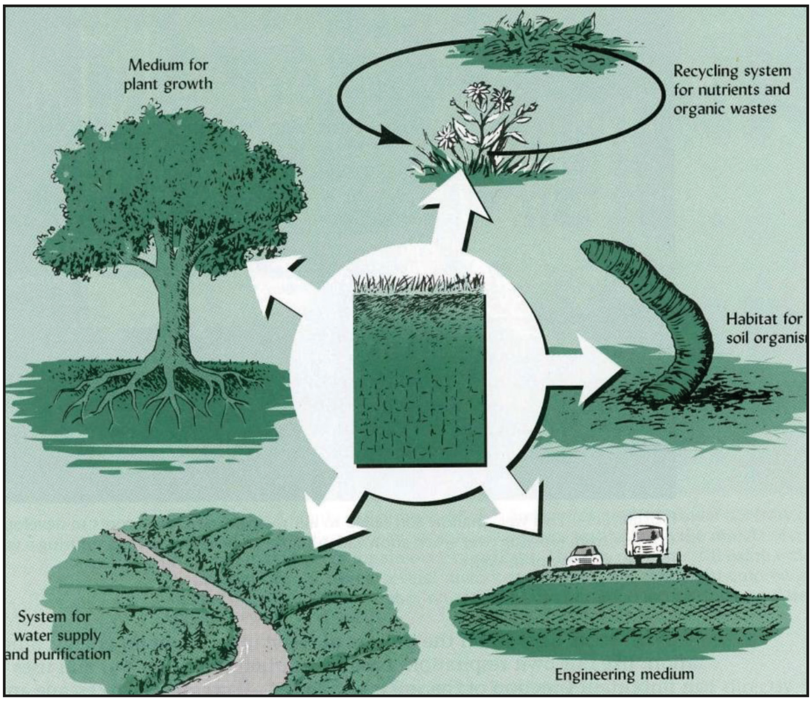
Soil functions

In our present World soil is much more than the most important medium for primary biomass production. Consequently, it has to be managed as a multifunctional natural resource and its other functions have to be taken into consideration in the activities for rational land use and sustainable soil management.The main soil functions in the Global Earth system are as follows (Figure 4) (Lal, 2002).

1

Soil is a **reactor and transformer.** It integrates the combined influences of other natural resources, such as solar radiation, atmosphere, surface and subsurface waters, deeper geological strata and biological resources. Their biogeochemical cycles develop a "life

Figure 4. Multifunctionality of soil

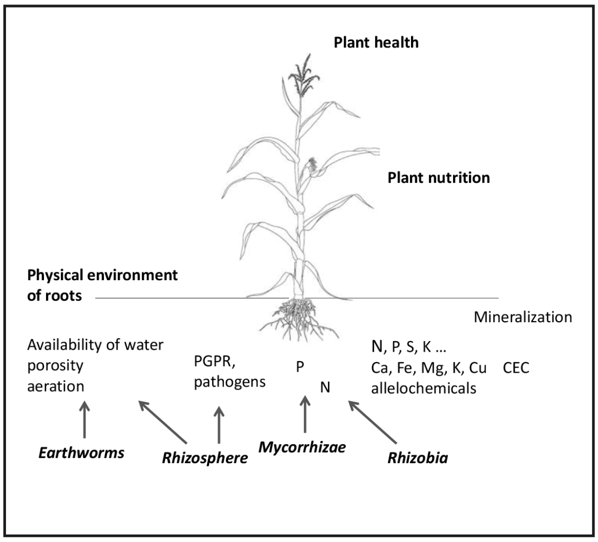


medium" for microbiological activities, and create ecological environment (standort, landsite) for natural vegetation and cultivated crops (Várallyay, 2000a).

2

Soil is the **most important medium for biomass production** (food, fodder, industrial raw material, alternative energy). Soil, as a four-dimensional [*spatial* (horizontal and vertical) variability and *temporal* dynamism], three- (or four-) phase, polydisperse system and can simultaneously satisfy – to a certain special extent – the ecological requirements (air, water and nutrient supply) of living organisms, the natural vegetation and cultivated crops (Figure 5). This special ability is the unique soil property: **soil fertility.** It varies greatly and has changed considerably depending on natural factors and human activities (Lal, 2002, Várallyay, 2002b, 2010a).

Figure 5. Soil as the medium of biomass



Soil is the primary food source of the biosphere, the starting point of the food chain (Soil Atlas of Europe, 2005). In addition to these „production" functions, soil has many environmental functions which are summarized in Figure 6 (Lal, 2002, Várallyay, 2000a, 2006).

3

Soils represent a major **natural storage capacity** of heat, water, plant nutrients and – in some special, well-controlled cases – wastes and other materials. The stored water and plant nutrients ensure the *continuous* water and nutrient supply of plants for shorter or longer periods without any additional supply (rain, irrigation, nutrient application). This soil function is the basis of favourable soil moisture

Figure 6. Environmental functions of soil

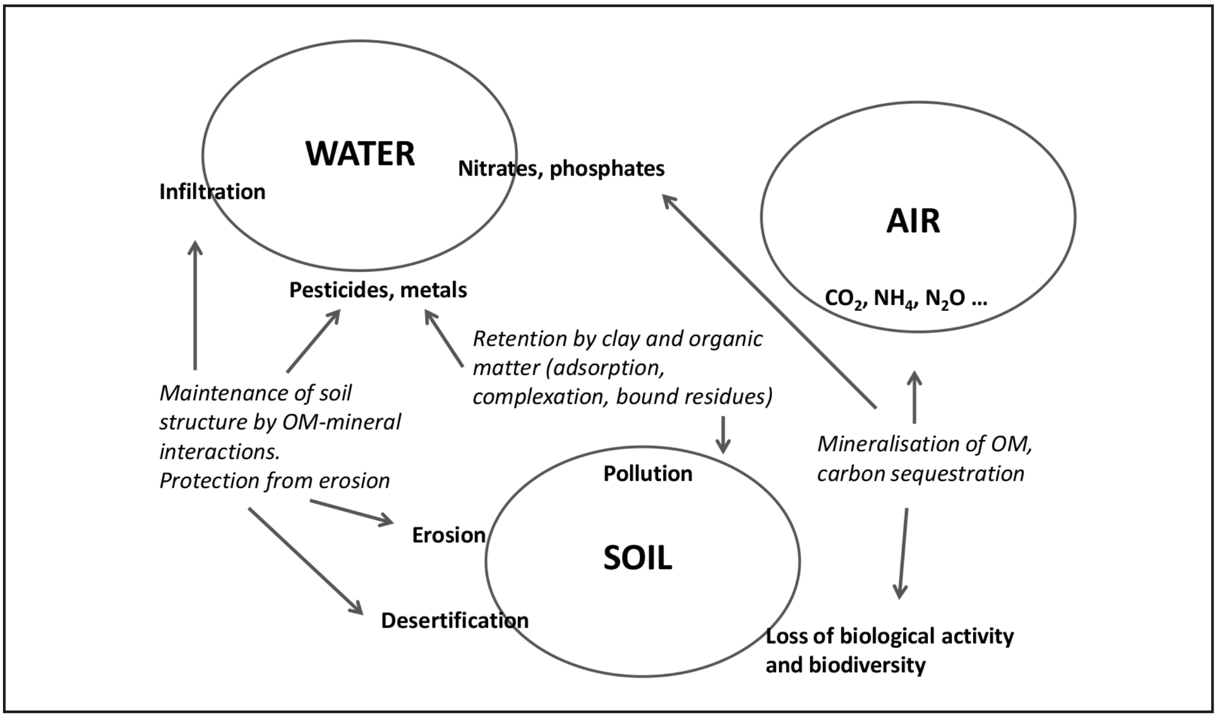


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Table 1. Major nutrient elements in soil

	Element	Ionic form taken up	Most important sources	Usual content
Major elements	Nitrogen N	NO_3^- NH_4^+	organic matter, N_2 from atmosphere	0.03–0.3%
	Phosphorus P	$H_2PO_4^-$ HPO_4^{--} (PO_4^{---})	Ca-, Al-, Fe-phosphate	0,01–0.1%
	Sulphur S	SO_4^{--}	Fe-sulphide, Fe-sulphate	0,01–0.1%
	Potassium K	K^+	micas, illite, K feldspar	0.2–3.0%
	Calcium Ca	Ca^{++}	Ca feldspar, augite, hornblende, $CaCO_3$, $CaSO_4$	0,2–1.5%*
	Magnesium Mg	Mg^{++}	augite, hornblende, olivine, biotite, $MgCO_3$	0.1–1.0%**

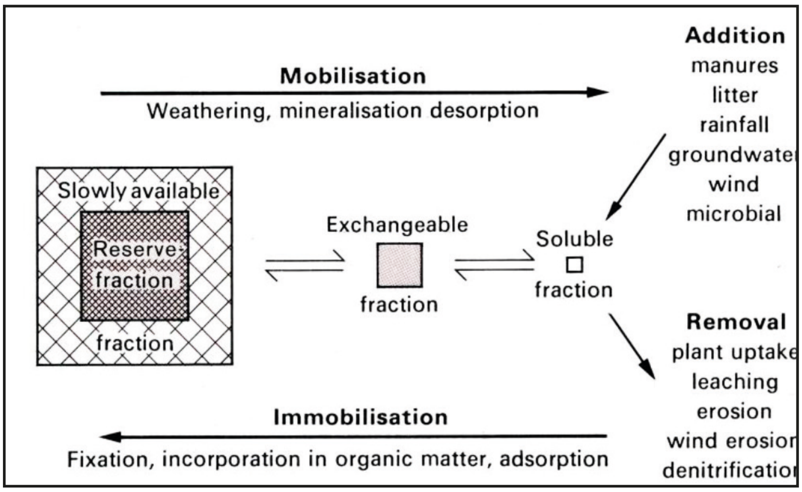
* Except chalk soils ** Except dolomitic soils

Table 2. Trace elements in soil

	Element	Ionic form taken up	Most important sources	Usual content
Trace elements	Boron B	$H_2BO_3^-$ (HBO_3^{--}) $(B[OH]_4^-)$	tourmaline, accessory in silicates and salts	5–100 ppm
	Molybdenum Mo	MoO_4^{--}	accessory in silicates, Fe- and Al-oxides and hydroxides	0.5–5 ppm
	Chloride Cl	Cl^-	various chlorides	50–> 1000 ppm
	Iron Fe	Fe^{++} Fe^{+++}	augite, hornblende, biotite, olivine, Fe-oxide and hydroxide	0.5–4.0%*
	Manganese Mn	Mn^{++} (Mn^{+++})	manganite, pyrolusite, accessory in silicates	200–4000 ppm
	Zinc Zn	Zn^{++}	Zn phosphate, $ZnCO_3$, Zn hydroxide, accessory in silicates	10–300 ppm
	Copper Cu	Cu^{++} (Cu^+)	Cu sulphide, Cu sulphate, carbonate, accessory in silicates	5–100 ppm

* Except Fe enriched horizons

Figure 7. Levels of nutrient availability and mechanisms influencing them



regime and sustainable plant nutrition (Németh et al., 2005, , Várallyay, 2010b). The **water storage function** (Várallyay, 2006, 2010b) has special significance in the Carpathian Basin, which is a greatly water dependent region. Here the generally favourable natural conditions show high and irregular (consequently hardly predictable) spatial and temporal variability, often extremes and sensitively react to various natural or human-induced stresses. Due to the irregularity of atmospheric precipitation, the increasing frequency of intense heavy rains („rain bomb"); heterogeneous macro-, meso- and microrelief; unfavourable soil properties; improper land use and cropping pattern the risk, frequency, duration and intensity intensity of **extreme meteorological and hydrological situations** (floods, waterlogging, over-moistening ⇔ drought) increase, often in the same year on the same territory.

Under such conditions it is an inevitably important fact that **soil is the largest potential natural water reservoir.** In ideal cases (potentially) in the pore volume of the 0–100 cm soil layer more than half of the 500–600 mm average annual atmospheric precipitation can be stored. About 50% of this quantity is „available moisture content" that may satisfy the water requirement of the natural vegetation and cultivated crops – even at high biomass production and yield levels. In many cases, however, this huge water storage capacity is not used efficiently because of the following limitations:

- limited infiltration (IR);
- limited water retention (FC);
- limited available moisture range (AMR).

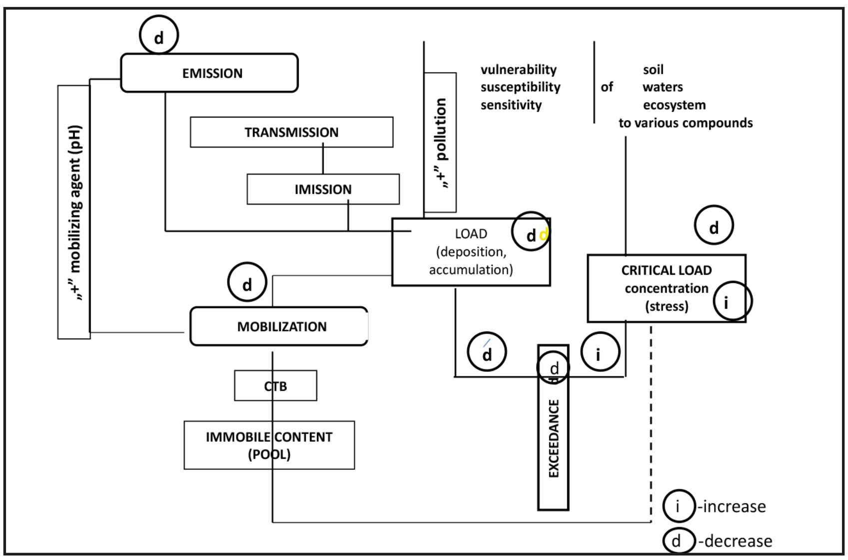
As a consequence of these limitations considerable **water losses** occur by surface runoff, evaporation, seepage and deep filtration. Soils with good agronomic structure may efficiently use the huge water storage capacity of soil and may and may reduce their unfavourable economical/environmental/ social consequences. On the contrary, the infiltration/storage limitations may even *magnify* these threats.

For the illustration of soil's element storage Table 1 indicates the major nutrient elements and Table 2 the trace elements in soil, showing their usual content and most important sources (Láng et al., 1983, Várallyay, 2010a). Figure 7 schematically summarizes their various forms and their mobilization/ immobilization mechanisms.

4

Soil represents a **high capacity buffer medium** of the biosphere, which, within certain limits, may moderate the various stresses caused by environmental factors (extreme temperature; extreme hydrological events: floods, waterlogging – droughts) and/or human activities (high input, fully-mechanized and chemically controlled crop

Figure 8. Strategy for soil pollution control



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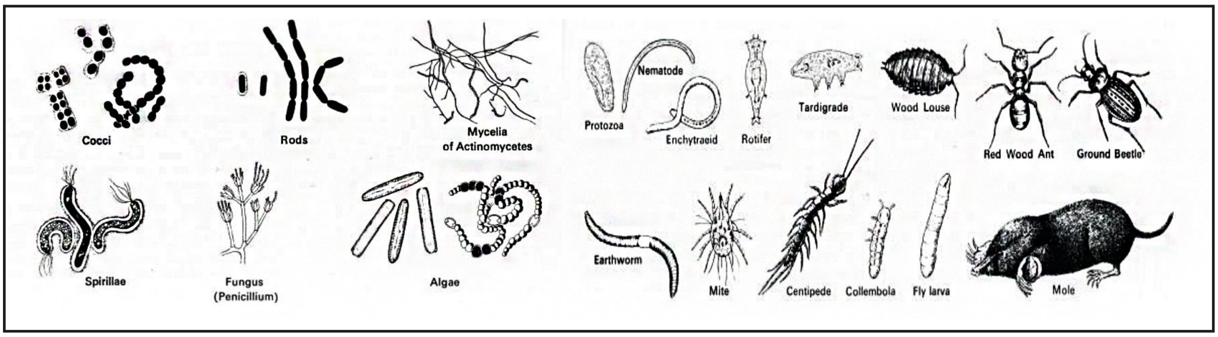
production; liquid manure from large-scale livestock farms; wastes and waste waters originating from industry, transport, urban and rural development, etc.). Buffer systems have strict limits and boundary conditions. Sometimes this is forgotten by the "users", which leads to serious environmental problems. To prevent and avoid unfavourable side-effects, the *tolerance limits* must be identified, precisely determined, quantified and evaluated. This requires comprehensive sensitivity (susceptibility, vulnerability) studies and impact analyses. Intensive international, regional and national studies have been carried out to determine these tolerance limits and target conditions (Soil Resolution of US, the Integrated European Soil Conservation Strategy and national soil conservation strategies (Soil Atlas of Europe, 2005) In Hungary comprehensive studies have identified and quantified the susceptibility/ sensitivity/vulnerability of soils to wind and water erosion, acidification, salinization/ alkalization/ sodification, physical soil degradation (compaction, structure destruction, surface sealing) and chemical pollution (Láng et al., 1983, Lal, 2002, Németh et al., 2005, Várallyay, 2006, Várallyay et al., 2010).

Figure 9. Living organisms in soil



5

Soil is an **efficient „natural filter" and detoxication system** that may prevent the deeper horizons and the subsurface waters from becoming contaminated by various pollutants deposited on the soil surface or put into the soil. Efficient *soil pollution control* (Figure 8) requires exact and quantitative information on the filter and detoxication „capacity" of soil, on the source and character of the pollutant(s) and on their interaction mechanisms.

6

Soil is a significant **gene reservoir** for the biosphere and thus an **important element of biodiversity.** A considerable proportion of living organisms live in or on the soil or are closely related to (sometimes depend on) the soil. Some examples are shown of these very different (size, shape, life, habitat, role in ecosystems and soil processes) organisms in Figure 9 (Lal, 2002, Soil Atlas of Europe, 2005).

7

Soil is the **conservator of natural and human heritages.**

8

Basis for constructions and other **soil sealing** activities: buildings and „urbanization" infrastructure; roads, highways, railways, aerodroms; water works (reservoires, ponds, canals, waterways, dykes, other hydrological constructions); open (surface) mines; waste-disposal establishments.

These activities (soil sealing) may cause irreversible, not or hardly correctable consequences, which means the decrease of multifunctional soil area, but does not mean that soil is lost and that it is a non-renewable natural resource.

Soil functions are all equally important, but the living organisms and their society

Table 3. Soil quality/health, as factors of sustainability

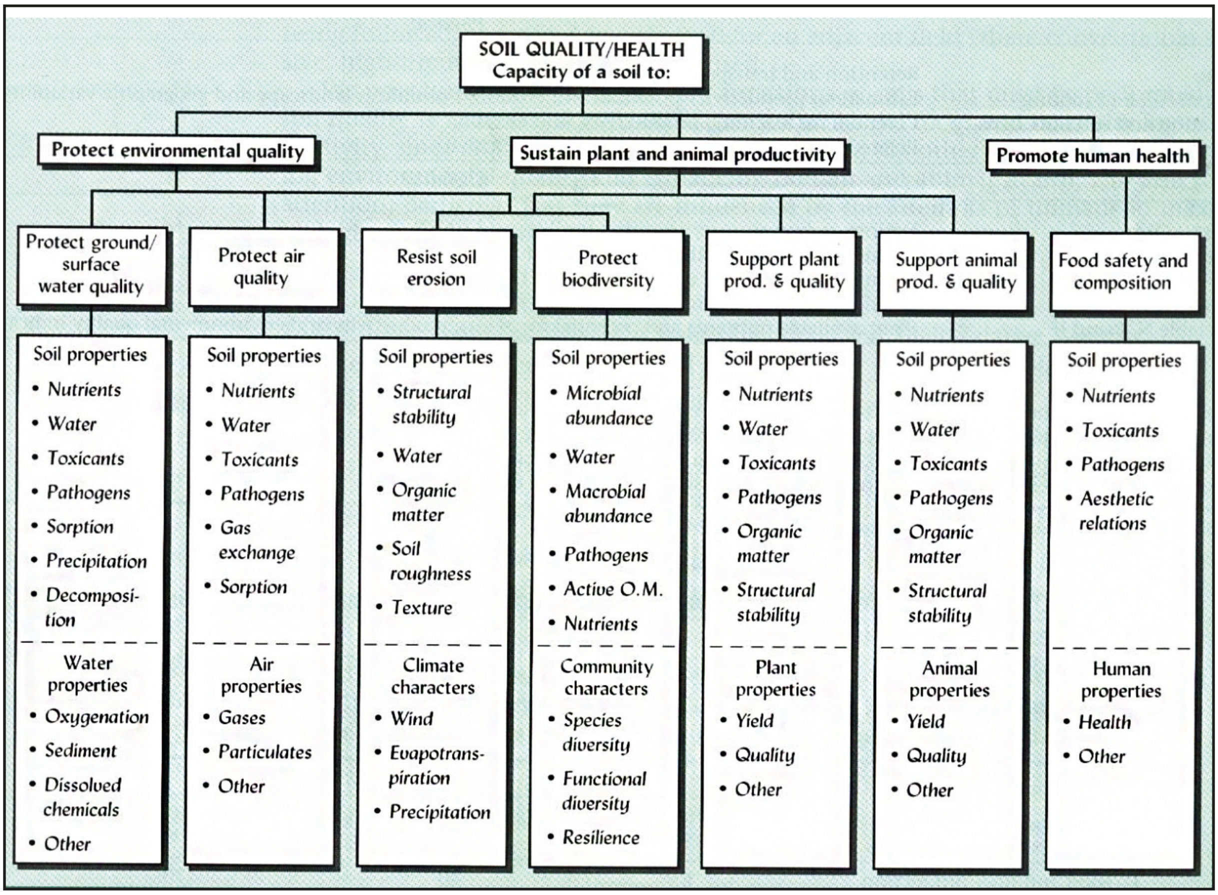
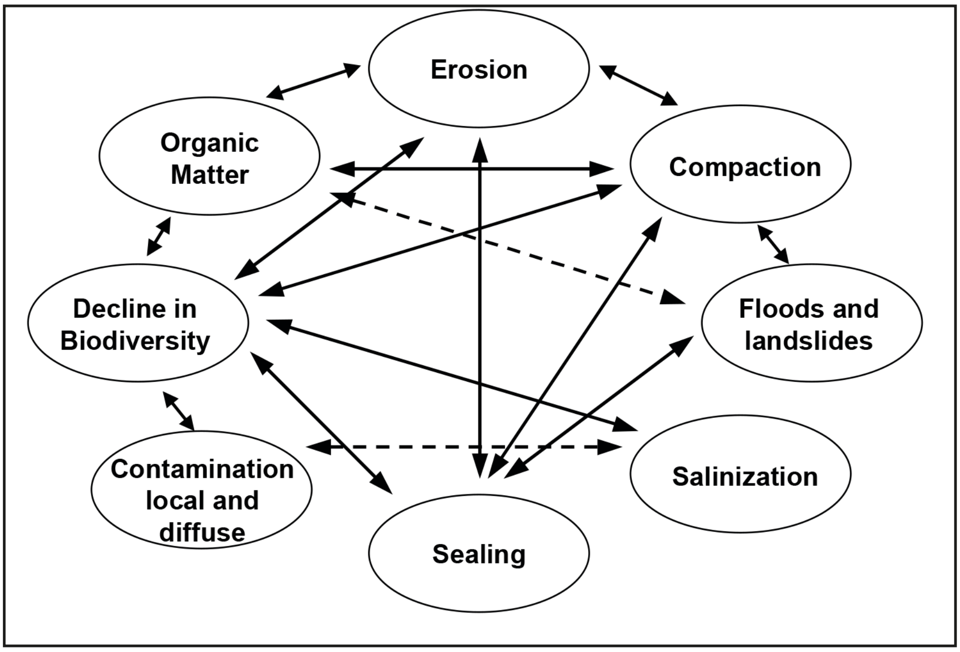


Figure 10. Land degradation problems in Europe



(even before the appearance of Man) have used them in different ways (rate, method, efficiency) throughout the natural or human history, depending on the given natural conditions and socio-economic circumstances. In many cases the character (territorial and temporal variabilities, changeability–stability–controllability,

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boundary conditions, limitations) of a certain function was not (properly or adequately) taken into consideration during the utilization of soil resources. In such cases the misguided management resulted in over-exploitation, decreasing the efficiency of one or more soil functions, and – abovea certain limit – causing serious environmental deterioration (Várallyay, 1997, 2003, 2010a).

Soil multifunctionality doesn't mean that a given soil is *equally* able to fulfill all of the various (sometimes contraversial) functions. It is the reason why *„soil quality" is not a general term,* but greatly *specific*, depending strongly on the main objective(s) and the *desired* function (Várallyay, 2000a). Rational and strict *priority setting* is crucially important in this respect! To help this priority setting Table 3 gives a list of soil properties and natural conditions for different „soil quality" assessments for sustainable biomass production, for the control of environment, and for the promotion of human health (Lal, 2002, Várallyay, 2000a).

Limiting factors of soil multifunctionality

In the **European Soil Conservation Strategy** eight soil degeradation processes (threats to soil multifunctionality) get priority distinction (Figure 10). In the **Carpathian Basin** (especially on the Carpathian plains) the natural conditions are **relatively favourable for rainfed biomass production. In spite of this fact a considerable part of** the soils are subject to various **ecological constraints** and **unfavourable soil processes** (Láng et al., 1983, Szabolcs and Várallyay, 1978, Várallyay, 2006, Várallyay et al., 2010):

(a) **Soil degradation processes.** The main

Figure 11. Positive and negative consequences of anthropogenic interventions on soil functions and soil processes

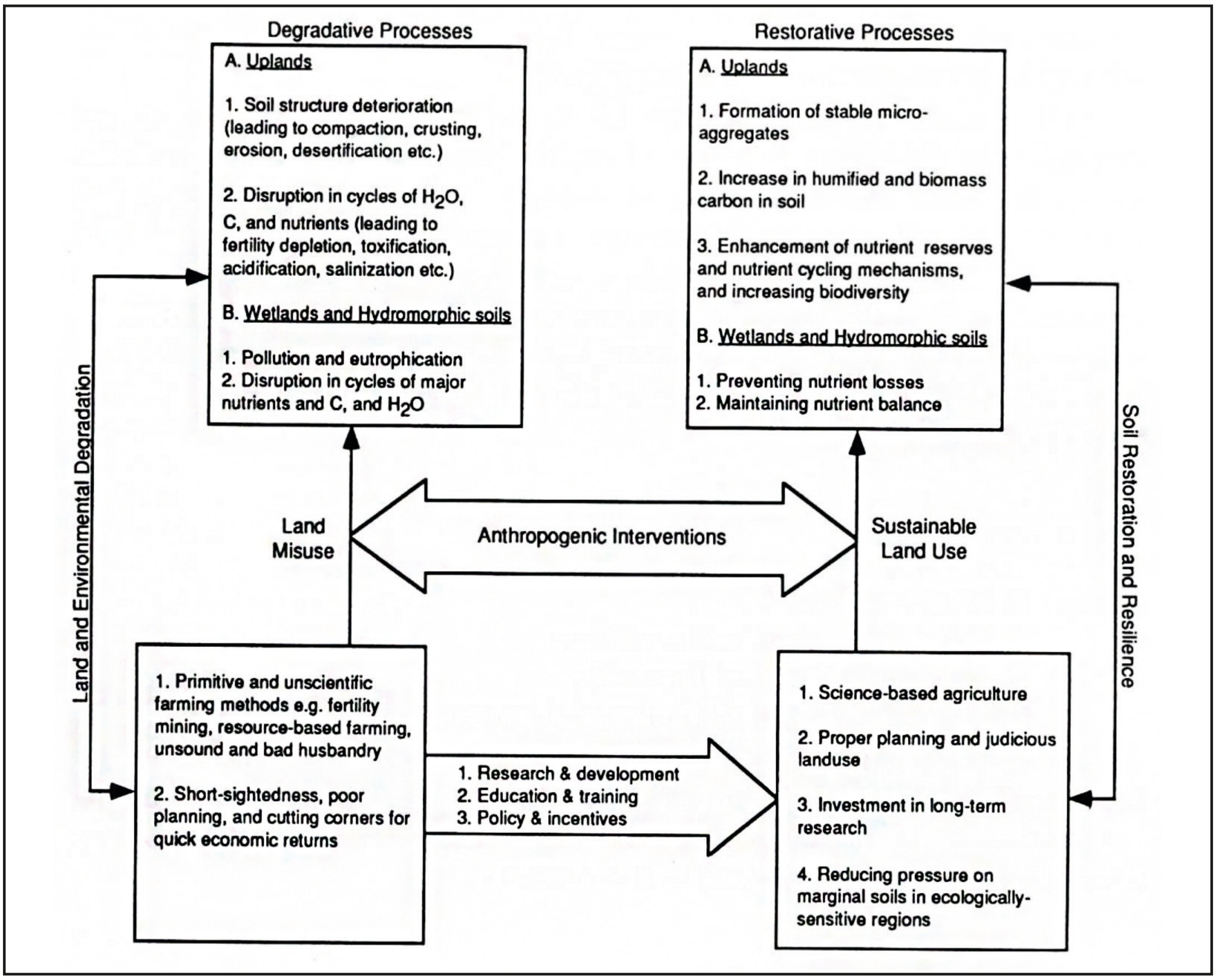
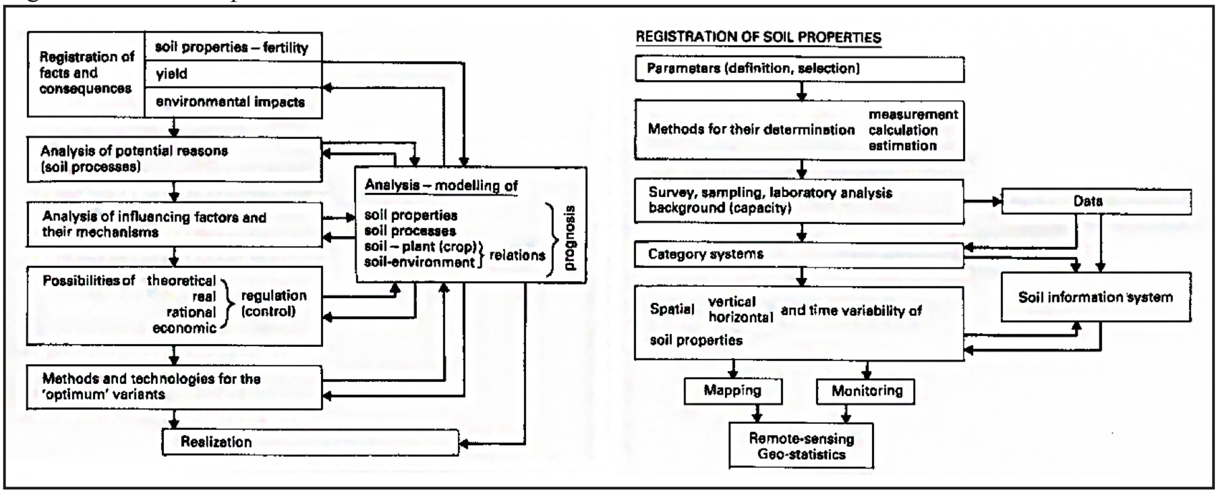


Figure 12. The conceptual model for the control of soil functions



soil degradation processes are: soil erosion by water or wind; soil acidification; salinization and/or alkalization; physical degradation (structure destruction, compaction); biological degradation; decrease in natural buffering capacity.

(b) **Extreme moisture regime:** the simultaneous hazard of waterlogging or over-moistening and drought sensitivity on large areas, sometimes in the same places within a short period.

(c) **Nutrient stresses.** The deficiency or accumulation and/or toxicity of one or more elements in the biogeochemical cycle.

(d) **Environmental pollution.** The accumulation or mobilization of various, potentially harmful (or even toxic) elements (or compounds) in the soil-water–plants–animals–human beings "food chain".

Control of soil functions

The **multifunctionality** of soil is determined by the combined influences of soil properties, which are the results of soil processes: mass and energy regimes, abiotic and biotic transport and transformation, and their interactions. Any direct or indirect soil-related activity influences the land through these processes. Consequently, the **control of soil processes** is a great challenge and the main task of soil science and soil management (Lal, 2002, Greenland and Szabolcs, 1993, Várallyay, 2000b). The positive and negative consequences of anthropogenic interventions on soil functions and soil processes are summarized in Figure 11. The conceptual model for the control of soil functions is shown in Figure 12 (Várallyay, 2000b).

The control of soil functions requires adequate **soil information**: exact, reliable, "detectable" (preferably measurable) and accurate, quantitative territorial data on well-defined soil and land properties, including the characterization of their spatial (vertical, horizontal) and temporal variabilities and pedotransfer functions; on the soil processes and biogeochemical cycles, including their determining and influencing factors and their mechanisms and on the actual and/or potential impacts of human activities. In Hungary a large amount of such information is available as a result of long-term observations, and various soil surveys, analytical and mapping activities conducted at the national (1:500,000), regional (1:100,000) farm (1:10,000–1:25,000) and field levels (1:5,000–1:10,000) over the past 60 years. A considerable part of these data were organized into a **GIS database** giving opportunities for an efficient control of soil processes and soil functions (Várallyay, 2000b, 2005).

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Conclusion

Soil is a four-phase, four-dimensional, polydisperse medium with three unique characteristics: conditionally renewable natural resource; resilience; multifuncionality. In addition to its primary function (fertility), the ability to produce multipurpose biomass (food, fodder, industrial raw material, alternative energy), modern society uses the other environmental (buffer, detoxication, biodiversity), technical (place and material for constructions, wellness) and even cultural (restore natural and human heritage) functions more and more intensely. Over- or irrational use sometimes are harmful threats to soil and may result in non- or hardly correctabl deterioration in soil multifunctionality, almost irreversible changes in ecosystems and – in acute cases – natural catastrophes with their tragical economical/ecological/environmental/social consequences. The rational and careful utilization and efficient **control of soil functions** is an inevitable task of *sustainability* for the enjoyable (but at least acceptable) life quality of present and future generations. Consequently, all efforts have to be taken – as priority – to maintain resilience, keep the renewable soil resources and create stable and sustainable conditions for their permanent renewal.

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