Soil Data-Base For Long-term Field Experiments and Sustainable Land Use

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Soils represent a considerable part of the natural resources of Hungary. Consequently, their rational utilization, conservation and the maintenance of their multipurpose functionality have particular significance in the Hungarian national economy and in environment protection.

The scientifically-based planning and implementation of *sustainable land use* and rational soil management ensuring normal soil functions require adequate *information on the soil:* exact, reliable, "detectable" (preferably measurable) and accurate, quantitative territorial data on well-defined soil and land properties with the characterization of their spatial (vertical, horizontal) and temporal variabilities, soil processes and pedotransfer functions. Similar soil information are necessary for the rational planning and establishment of long-term field experiments and for the multipurpose interpretation of their results. The main objective of the present paper is to give a comprehensive overview on these available and applicable soil data.

Soil Functions

The main functions of soil in the biosphere are as follows (VÁRALLYAY, 1993):

1. Soils are the most significant - *conditionally renewable - natural resources.* During crop production they do not change irreversibly, their quality does not decrease unavoidably and fundamentally. But their "renewal" does not go on automatically: soil conservation, the maintenance and increase of soil fertility requires permanent activities, such as: sustainable land use, agrotechnics, remediation and reclamation.

2. Soil, as *reactor, transformator and integrator* of the combined influences of other natural resources (solar radiation, atmosphere, surface and subsurface waters, biological resources) represents the "life-media" for microbiological

activities, as well as the ecological environment for natural vegetation or cultivated crops);

3. Soil is the most important *medium for biomass production.* Water, air and available plant nutrients may occur simultaneously in soil, in this four-dimensional, three-phase, polydisperse system and soil may provide the principal requirements of plants.

4. Soil is a major *natural storage* of heat, water and plant nutrients.

5. Soil is an efficient *"natural filter"* and may prevent various pollutants from reaching the deeper horizons and the sub-surface waters.

6. Soils represent a *high capacity buffer medium* of the biosphere, which, to a certain limit, may moderate the various stresses caused by environmental factors (climatic droughts or too humid conditions, frost, etc.) and/or human activities (high input, fully-mechanized and chemically controlled crop production; liquid manure from large scale livestock farms; wastes and waste waters originating from industry, transport, and rural developments; etc.).

7. Soil is an important *gene reservoire* and a significant element of *biodiversity.*

The ability of soil to fulfil these functions (*"soil value"*) is determined by the integrated impacts of various *soil properties,* which are the results of *soil processes:* mass and energy regimes, abiotic and biotic transport and transformation and their interactions. As any soil-related human activity influences the soil through these processes, their control is the main task of soil science and soil management. The Hungarian "strategy" for the *control of soil processes* is summarized in Figure 1.

Soil Forming Factors, Soil Formation Processes and Soils of Hungary

Soil forming factors (Figure 2) show high spatial and temporal variability in Hungary. The present soil cover of the country has developed mainly in the Quaternary (Pleistocene) and in the Holocene geological periods and a considerable part is of recent formation.

The main characteristics of the basic soil forming factors are briefly summarized in the following.

- The surface (or near to surface) *geological deposits* (parent material) vary widely in origin, mineral and chemical composition, particle size and weathering resistance: aeolian sand and various alluvial (← fluviatile activity) and colluvial (← lateral erosion) deposits (37.7%); Quaternary loess (deposited partly to dry surfaces, partly into water or waterlogged areas during the Pleistocene interglacial periods (48.0%); Tertiary or older sediments (including the heavy-textured and saline deposits of the Pannonian sea) (7.5%); and various sedimentary, igneous and volcanic rocks and their weathering products (6.8%).

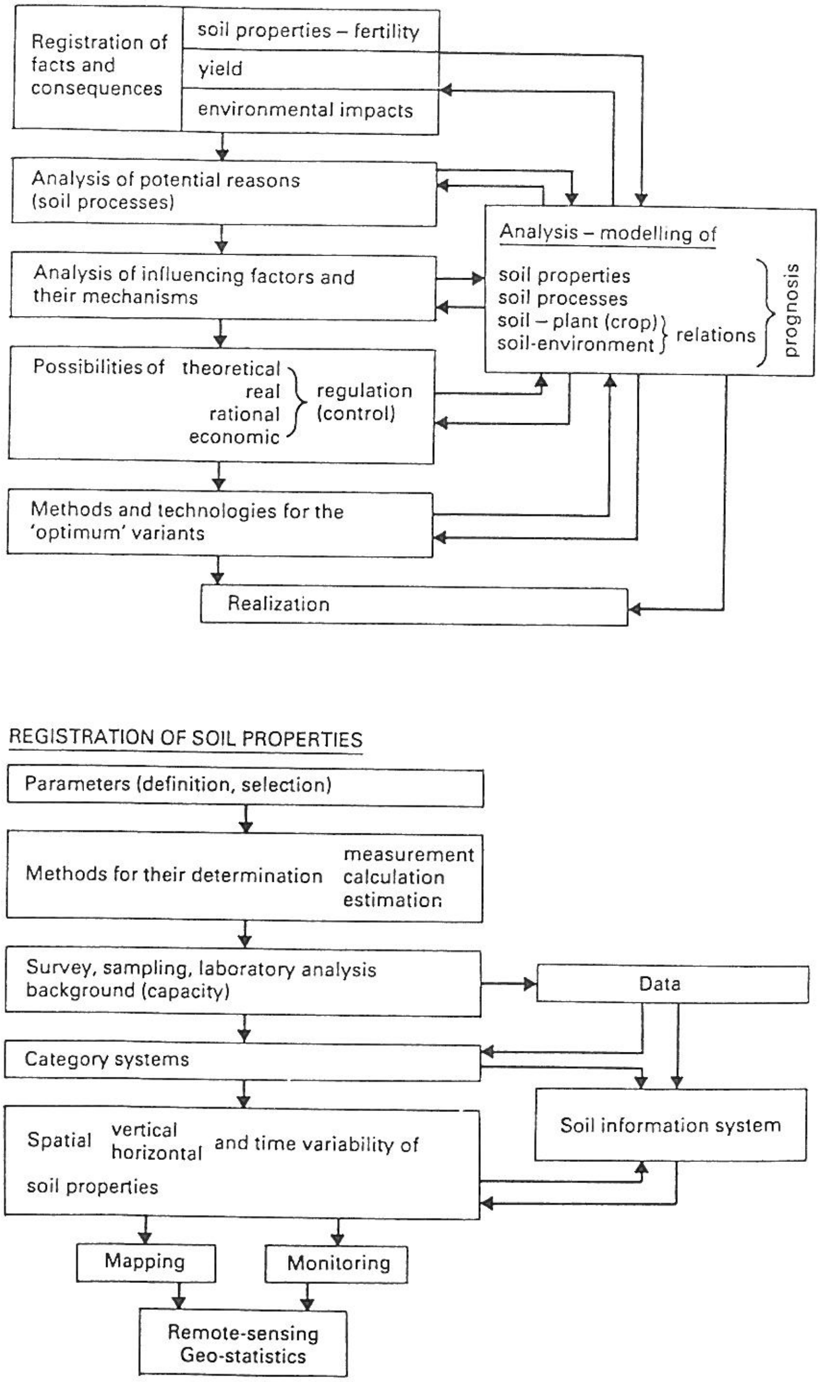

Figure 1
Control of soil processes

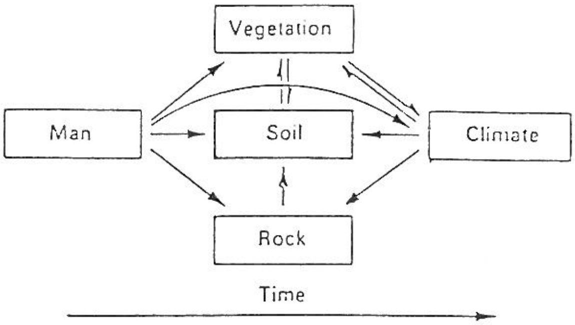

Figure 2
Factors of soil formation

- The *weather* is under the combined and changing influences of the Atlantic, Continental and Mediterranean climates and shows particularly wide spatial and temporal variability. The average annual temperature is 10.5 °C (the monthly average in January is -2.5 °C, while it is 25.0 °C in August). The average annual precipitation is 550-700 mm, ranging between the 450-500 mm annual value in the driest part of the Hungarian Plain and 800-900 mm in the Western Prealpian Region.
- Both *surface and subsurface hydrology* of the country are determined by the fact that Hungary is situated in the deepest part of the hydrologically (the only drainage outlet is the Danube) and hydrogeologically (practically no subsurface outflow) closed Carpathian Basin. The majority (85-90%) of the rivers flow through the country and Hungary has to guarantee a certain water quantity and quality in these rivers at the Southern borders for the low-Danube countries. The water balance of the Hungarian Plain is negative (potential evapotranspiration, ET is higher than precipitation, P) and this deficit is equilibrated by horizontal inflow: surface runoff, R; seepage in the unsaturated zone, S; and groundwater flow, G:

$$\text{if} \quad ET > P, \text{ then}$$
$$R_i + S_i + G_i > R_o + S_o + G_o$$
$$\text{and} \quad P + R_i + S_i + G_i \approx ET + R_o + S_o + G_o$$

which is equilibrium for water, but accumulation for soluble materials.
- The *natural vegetation* (determined by climatic factors, relief and moisture regime (wetting conditions) was forest steppe and various wetland ecosystems in the Carpathian Basin.
- Its role was considerably modified by the *activities of man* both directly (deforestation; grazing; flood control; intensive agricultural use, including chemization, mechanization, amelioration, irrigation and drainage, etc.) and indirectly (human-induced stresses, soil degradation and soil pollution, landscape deterioration, etc.).

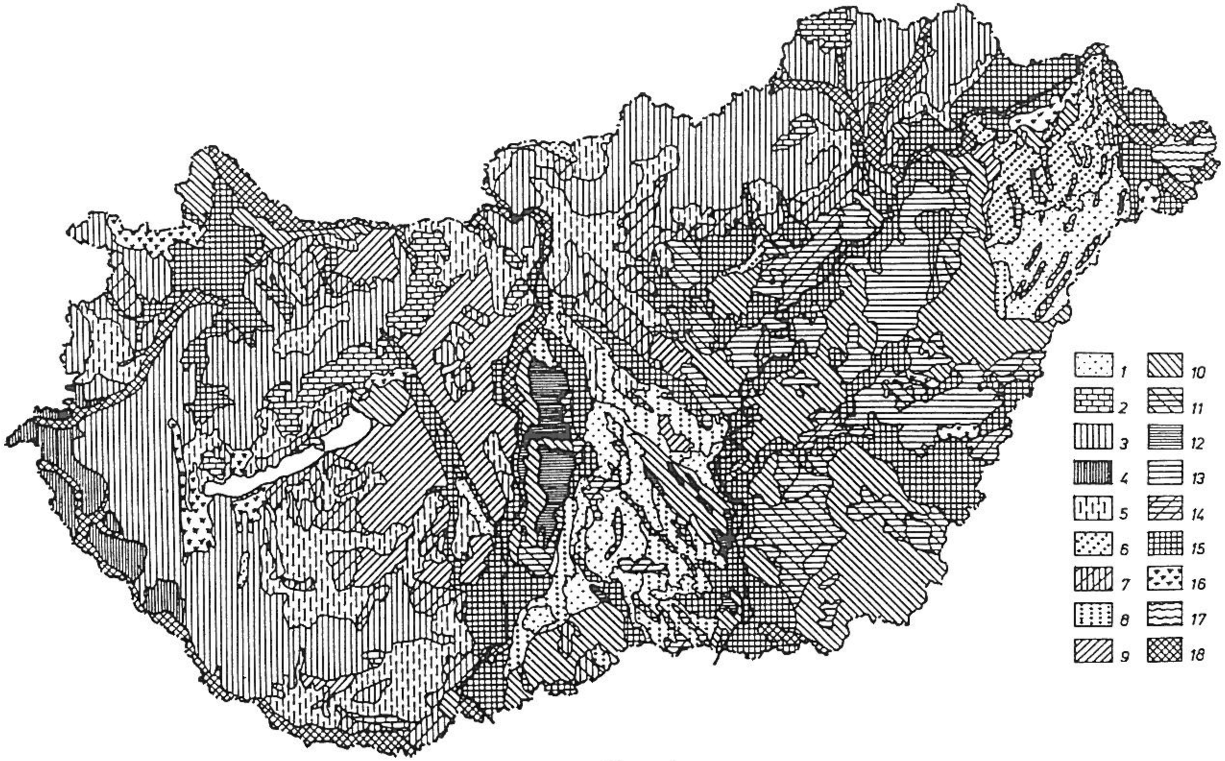

Figure 3

Soil Map of Hungary (simplified, schematic version of the original 1:100,000 scale map). 1. Blown sand, humous sandy soils; 2. Rendzinas, erubase soils, "nyirok". 3. Lessivated brown forest soil. 4. Pseudogleys. 5. Brown earths (Braunerde). 6. Brown forest soils with alternating thin layers of clay substance ("kovárvány"). 7. Chernozem brown forest soils. 8. Chernozem-type sandy soils. 9. Pseudomyceliar (calcareous) chernozems. 10. Lowland chernozems, meadow chernozems (the term "meadow" is related to hydromorphic character), terrace chernozems. 11. Lowland chernozems with salt accumulation in the deeper layers, meadow chernozems with salt accumulation in the deeper layers, solonetzic meadow chernozems. 12. Solonchaks, solonchak solonetzes. 13. Meadow solonetzes, meadow solonetzes turning into steppe formation. 14. Solonetzic meadow soils. 15. Meadow soils, peaty meadow soils. 16. Peat, ameliorated peat. 17. Soils of swampy forests. 18. Alluvial soils. The stony soils (solid rock is on or near the surface) and the acidic, non-podzolic brown forest soils are not indicated in the map because of their negligible occurrence.

Table 1

Territorial distribution of the various soil factors determining the agroecological potential in Hungary (in hectares)

Soil factors determining the agro ecological potential	Total	%
Parent material		
1 Glacial and alluvial deposits	3 433 430	37.7
2 Loess, loess-like deposits	4 374 920	48.0
3 Tertiary and older deposits	681 440	7.5
4 "Nyirok"	151 660	1.7
5 Limestone, dolomite	238 950	2.6
6 Sandstone	11 430	0.1
7 Shale, phyllite	28 530	0.3
8 Granite, porphyryt	9 740	0.1
9 Andesite, riolite, basalt	179 350	2.0
Soil reaction and carbonate status		
1 Strongly acidic soils	1 228 930	13.5
2 Slightly acidic soils	3 848 550	42.2
3 Calcareous soils (effervescence with dilute acid from the surface)	3 493 090	38.4
4 Salt affected soils, calcareous from the surface	385 260	4.2
5 Salt affected soils, non-calcareous from the surface	153 620	1.7
Soil texture		
1 Sand	1 437 230	15.8
2 Sandy loam	875 460	9.6
3 Loam	3 932 320	43.2
4 Clay loam	1 692 630	18.6
5 Clay	632 840	6.9
6 Organic soils (peat, partly decomposed peat)	117 560	1.3
7 Coarse fragments (gravel, non- or partly weathered rocks, etc.)	421 410	4.6
Soil-water management properties		
1 Soils with very high infiltration rate (IR), permeability (P) and hydraulic conductivity (HC); low field capacity (FC); and very poor water retention (WR)	957 420	10.5
2 Soils with high IR, P and HC; medium FC, poor WR	1 009 910	11.1
3 Soils with good IR, P, and HC; good FC; and good WR	2 264 230	24.9
4 Soils with moderate IR, P and HC; high FC, and good WR	1 735 640	19.1
5 Soils with moderate IR, poor P and HC; high FC; and high WR	571 080	6.2
6 Soils with unfavourable water management: low IR, very low P and HC and high WR	1 349 750	14.8
7 Soils with extremely unfavourable water management; very low IR, extremely low P and HC; and very high WR	329 210	3.6
8 Soils with good IR, P and HC and very high FC	117 560	1.3
9 Soils with extreme moisture regime due to shallow depth	774 650	8.5
Organic matter content ($t\ ha^{-1}$)		
1 < 50	481 750	5.3
2 50–100	1 915 130	21.0
3 100–200	2 596 270	28.5
4 200–300	1 923 590	21.1
5 300–400	1 887 270	20.7
6 > 400	305 440	3.4
Depth of the soil (limited by solid or slightly fragmented rocks, gravel, cemented layers, pans, peat, loose sand, groundwater, etc.)		
1 < 20 cm	25 780	0.3
2 20–40 cm	445 260	4.9
3 40–70 cm	480 310	5.3
4 70–100 cm	370 630	4.0
5 > 100 cm	7 787 470	85.5
TOTAL	9 109 450	100.0
Lakes	95 900	
Towns	98 150	
Total area of the country	9 303 500	

The combined influences of these soil forming factors with high spatial and temporal variability create extremely heterogeneous physico-geographical environment for soil formation processes, which results in the mosaic-like variability of soils and their properties in Hungary (Figure 3, Table 1).

The processes of soil formation and the occurrence and geographical distribution of various soils can be well illustrated by the development of various soil sequences:

1. Chrono-sequence.

If the changing factor is time (duration of pedogenesis) the result is a sequence from unaltered parent material (alluvium, colluvium, weathered rocks, etc.) to well-developed soils with differentiated soil profiles:

I. In a loess plateau or aeolian (wind deposited) sand region:

loess ↘ / aeolian sand ↗	weakly humous	loess / sandy	soil	→	humous	loess / sandy soil	→ well-developed soil type e.g. chernozem or brown forest soils

II. In an alluvial plain:

recent alluvium	→	alluvial soil	→	humous alluvial soil	→	well-developed soil types	↗ alluvial meadow soil (hydromorphic soil under the permanent influence of groundwater) ↘ terrace chernozem (soil formed without groundwater influence)

III. In a slightly undulating hilly area:

limestone, dolomite, igneous, volcanic rocks	→	weathered rocks with slight humus accumulation in the top horizon	→	brown rendzina → black rendzina
			→	brown forest soils, podzols

recent colluvium	→	colluvial soil	→	humous colluvial soil	→	well-developed soil types	→	hydromorphic soils

2. Topo-sequence (Catena)

Catena is a sequence of soils of about the same age, derived from similar parent material, and occurring under similar climatic conditions, but having different characteristics due to the variation in relief, in drainage conditions and in moisture regime (intensity of wetting).

In Hungary the main steps of the topo-sequence are as follows:

chernozem (without any groundwater influence)
↓
meadow chernozem (slight groundwater influence in the deeper horizons)
↓
chernozem meadow soil (moderate groundwater influence periodically)
↓
meadow soil (permanent groundwater influence)
↓
peaty meadow soil (strong and permanent groundwater influence, with periodical waterlogging)
↓
peat (permanent or frequent waterlogging).

Another type of topo-sequence (catena) is the *erosion sequence*:

upper slope:	slightly eroded soils ↓
mid slope:	heavily eroded soils ↓
lower slope:	non-eroded soils; soils buried by colluvial sediments and materials eroded from the upper parts of the slope.

3. Leaching sequence

In this case the different rate of downward flow (due to high atmospheric precipitation and/or surface seep-in) results in the different intensity of leaching and rate of profile differentiation:

chernozem brown forest soil ↓	minimum rate of leaching: only water soluble salts are leached completely; there is a moderate leaching of carbonates; no clay movement → no textural B horizon
Ramann brown forest soil ↓	moderate leaching of carbonates; no significant clay movement → no textural B horizon

brown forest soil with clay illuviation ↓	leaching of carbonates; clay movement → well-developed textural B horizon
pseudogley ↓	strong clay illuviation to the well-developed structural B horizon, and periodical stagnant water formation above this compact, near to impermeable layer
podzol	strong leaching and destruction of soil's organo-mineral complex, and mineral part: SiO_2 (accumulated); R_2O_3 (leached down)

4. Salinity-alkalinity sequence

If the changing factor is the salinity-alkalinity status, the following sequence can be distinguished:

solonchak ↓	very high salinity from the surface
solonchak-solonetz ↓	high salinity near to the surface
	low salinity in the A horizon:
shallow meadow solonetz ↓	A horizon < 7 cm; ESP > 25% in B horizon
medium meadow solonetz ↓	A horizon 7-15 cm; ESP > 25% in B horizon
deep meadow solonetz turning into steppe formation ↓	A horizon > 15 cm; ESP > 25% in B horizon
solonetzic meadow soil ↓	ESP 5-15% in the B horizon
soils with salinity-alkalinity in the deeper horizons	low salinity-alkalinity in the A and B horizons

The soil cover of Hungary shows a "super matrix" of these sequences with their numerous combinations, which is schematically illustrated in Figure 3 (VÁRALLYAY, 1989).

Data Sources on Natural Factors

In Hungary a large amount of information are available on the various natural factors as a result of long-term observations, survey and mapping activities (The National Atlas of Hungary, 1989). The most important data bases and monitoring systems are as follows:

a) *Meteorological data.* Systematic and regular measurements from 1850. At present the basic meteorological parameters are registered at 160 observation points; 18 stations are equipped for detailed atmospheric-chemistry measurements and 4 EMEP stations for continuous atmospheric monitoring (MÉSZÁROS et al., 1993).

b) *Hydrological data.* Regular records on the quantity and quality of *surface waters* (rivers, creeks, canals, lakes, ponds, reservoirs) from the first decade of the century.

Data on *groundwater conditions* (depth of water table; chemical composition of the groundwater) in 600 - 1000 groundwater testing wells are available from 1935, including 50 piezometer installations, measuring of pressure conditions and water chemistry parameters in the various deeper aquifers. On this basis the 1:200,000 scale map of the average depth to the groundwater table, and the 1:100,000 scale map of the groundwater chemistry (total concentration, ion composition) had been prepared and updated; and a 1:1 M scale map on the actual depth of the groundwater table was edited monthly during the seventies.

c) *Geological data.* As a result of the 160-year geological survey, a 1:200,000 geological map for the whole country and a great number of various thematic geological, hydrogeological, geo-chronological maps have been prepared in larger scales for different regions of the country.

d) *Geomorphological data.* The 1:200,000 geomorphological map showing the various geomorphological types, subtypes and varieties of Hungary is available with a series of regional maps indicating the geomorphology pattern of a smaller territory in larger scale. In addition to the traditional contour maps the relief characteristics (slope gradient, length, complexity, exposure of the slopes) are indicated on a special "relief map" (1:100,000) prepared during the last years with the application of computerized digital relief models.

Soil Information Sources

A large amount of soil information are available in Hungary as a result of long-term observations, various soil survey, analyses and mapping activities on national (1:500,000), regional (1:100,000), farm (1:10,000-1:25,000) and field level (1:5,000-1:10,000) during the last sixty years. Thematic soil maps are available for the whole country in the scale of 1:25,000 and for 70% of the agricultural area in the scale of 1:10,000.

There are at least three reasons why this rich soil database has been developed (VÁRALLYAY, 1993):

1. The small size of the country (93,000 km²);
2. The great importance of agriculture and soils in the national economy;
3. The historically "soil loving" character of the Hungarian people, and particularly the Hungarian farmers.

Soil Maps

In Table 2 the most important thematic soil maps in Hungary are summarized, indicating their content, scale, author and date of preparation (Proceedings of the Hungarian-Swedish Seminar on Soil Mapping, 1989; STEFANOVITS & SZÜCS, 1961; VÁRALLYAY, 1989).

As it can be seen from Table 2, the maps can be divided into three main groups:

(a) *Large-scale maps* (Nos. 1.-4. in Table 2)

(1) In the "Kreybig - *practical soil maps*" (KREYBIG, 1937) the soil reaction, carbonate and salinity/alkalinity status is indicated by colours; physical-hydrophysical characteristics and depth of the soil by rasters; the organic matter, total P_2O_5 and K_2O content, depth of the humus horizon and depth of the groundwater table by a code number; and the soil type (according to 'Sigmond's soil classification) with roman numbers.

(2) On the 1:10,000 scale *genetic soil maps* (SARKADI et al., 1964; SZABOLCS, 1966) the most important soil properties (soil type, subtype and local variant according to the Hungarian soil classification system; pH and carbonate status; texture; hydrophysical properties; salinity/alkalinity status; organic matter resource; N, P and K status) are indicated on separate thematic maps (cartograms); and recommendations are summarized in additional thematic maps for rational land use and cropping pattern; soil cultivation; rational use of fertilizers; soil moisture control, including water conservation practices, irrigation and drainage; soil conservation practices for water- and wind erosion control; etc.

(3) The large-scale maps on the *possibilities and limitations of irrigation* (SZABOLCS, DARAB & VÁRALLYAY, 1969) indicate:

- soil types, subtypes and local variants and parent material;
- physical-hydrophysical soil characteristics;
- salinity/alkalinity status of the soil (salt content, ion composition, ESP, pH);
- groundwater conditions (depth and fluctuation of water table; salt concentration, ion composition and SAR of the groundwater)

and on this basis:

- the "critical depth" of the water table and "critical groundwater regime";
- recommendations for irrigation practices and groundwater management

on separate thematic maps.

Table 2
Thematic soil maps in Hungary

No.	Map	Scale	Date of preparation	Prepared for	Content	Author(s)	References
1.	Practical soil maps	1:25,000	1935-1955	the whole country per topographical map sheets	m, tm, fd, ld, e	Kreybig and coll.	VÁRALLYAY, 1985, 1989
2.	Large-scale genetic soil maps	1:10,000	1960-1975	60% of the agricultural land of Hungary, per farming units	m, tm, fd, ld, e	Coll.	SZABOLCS, 1966
3.	Soil conditions and the possibilities of irrigation	1:25,000	1960-1970	present and potential irrigated regions	6 thematic maps fd, ld	Coll.	SZABOLCS et al., 1969
4.	Large-scale maps for amelioration projects	1:5,000-1:10,000	1960-	amelioration projects (occasionally)	m, e	Coll.	
5.	Soil factors determining the agro-ecological potential	1:100,000	1978-1980	the whole country per topographical map sheets	m (with an 8-digit code), c	Várallyay, G. Szücs, L. Murányi, A. Rajkai, K. Zilahy, P.	VÁRALLYAY et al., 1979, 1980a
6.	Agro-topographical map	1:100,000	1987-1988	the whole country per topographical map sheets	m (with a 10-digit code), c	Várallyay, G. Molnár, S. Szücs, L.	VÁRALLYAY & MOLNÁR, 1989
7.	Hydrophysical properties of soils	1:100,000	1978-1980	the whole country per topographical map sheets	m, c	Várallyay, G. Szücs, L. Rajkai, K. Zilahy, P.	VÁRALLYAY, et al., 1980b

No.	Map	Scale	Date of preparation	Prepared for	Content	Author(s)	References
8.	Limiting factors of soil fertiltiy	1:500,000	1976	the whole country	m	Szabolcs, I. Várallyay, G.	SZABOLCS & VÁRALLYAY, 1978
9.	Main types of moisture regime	1:500,000	1983	the whole country	m, c	Várallyay, G. Zilahy, P. Murányi, A.	VÁRALLYAY, 1985
10.	Main types of substance regime	1:500,000	1983	the whole country	m, c	Várallyay, G. Szücs, L. Molnár, E.	VÁRALLYAY, 1985
11.	Soil erosion	1:500,000	1960-1964	the whole country	m, tm, e	Stefanovits, P. Duck, T.	STEFANOVITS, 1964
12.	Salt affected soils	1:500,000	1970-1974	the whole country	m, e	Szabolcs, I. Várallyay, G. Mélyvölgyi, J.	SZABOLCS, 1974
13.	Susceptibility of soils to acidification	1:100,000 1:500,000	1985-1988	the whole country	m, c	Várallyay, G. Rédly, M. Murányi, A.	VÁRALLYAY et al., 1993
14.	Susceptibility of soils to physical degradation	1:500,000	1985-1988	the whole country	m, c	Várallyay, G. Leszták, M.	VÁRALLYAY & LESZTÁK, 1990.
15.	Soil evaluation	-	1980-1985	soil profiles	fd, ld	Coll.	
		1:10,000 1:25,000	1985-	non-mapped part of agricultural and forest land of Hungary	m, tm, f, ld	Coll.	

Remarks:
m: soil map; tm: thematic map; fd: field description; ld: laboratory data; e: explanatory booklet; c: computer storage

(4) Large scale (1:5,000, 1:10,000) maps for various *soil amelioration projects.*

(b) Medium scale maps (Nos 5-7 in Table 2).

(1) In 1978 a national programme was initiated by the Hungarian Academy of Sciences for the "Assessment of the agro-ecological potential of Hungary". In this programme a 1:100,000 scale map was prepared by the author's team (VÁRALLYAY et al., 1979, 1980a) on the *soil factors determining the agro-ecological potential,* utilizing all available soil information. On the map 7 soil factors were indicated with an 8-digit code number:

1st and 2nd digit: Soil types (31 categories);
3rd digit: Parent material (9 categories);
4th digit: Soil reaction and carbonate status (5 categories);
5th digit: Soil texture (7 categories);
6th digit: Hydrophysical properties (9 categories);
7th digit: Organic matter resource (6 categories);
8th digit: Depth of the soil (5 categories).

The territorial data of the map are summarized in Table 1.

The map was completed later with two additional code numbers expressing two further soil characteristics:

9th digit: Clay mineral associations of soil (STEFANOVITS, 1989);
10th digit: Soil productivity index.

(2) The contours of these 9 soil characteristics were printed on a 1:100,000 scale basic topographical map with rich information content (relief, surface waters, land use, infrastructure, etc.). Meteorological information are given on the territorial and temporal variability of the main climate elements on each map sheet by "micro-maps" and monthly distribution diagrams, respectively. These *agro-topographical maps* were prepared for the whole country and are available in printed form per topographical sheets (VÁRALLYAY & MOLNÁR, 1989).

The soil contours of the agro-topographical map were digitized and organized into a GIS-based soil information system (see later).

(3) The map of the categories of the *hydrophysical properties of soils* were also prepared in the scale of 1:100,000. The 9 main and 17 subcategories indicated were defined by the following soil characteristics: texture, saturation percentage (SP); field capacity (FC), wilting percentage (WP), available moisture range (AMR); infiltration rate (IR), saturated hydraulic conductivity (K), unsaturated capillary conductivity (k, k-Ψ or k-θ); and by the layer-sequence of the soil profile (VÁRALLYAY et al., 1980b).

(4) Maps on the *status of soil erosion* have been prepared by STEFANOVITS and his team in the 50's for the agricultural lands of hilly regions in Hungary. On the 1:75,000 scale maps the following categories were indicated: strongly, moderately and slightly eroded lands; areas of sedimentation; territories under

the influence of wind erosion. In addition to these erosion characteristics parent material was also indicated on the maps (STEFANOVITS, 1964).

(c) *Small scale maps*

(1) 1:500,000 scale generalized thematic soil maps (Nos 8-12 in Table 2)

(2) 1:500,000 scale HunSOTER (HUNgarian SOil and TERrain digital database) (VÁRALLYAY et al., 1994);

(3) 1:1,000,000 - 1:5,000,000 scale soil maps, prepared for various international programmes, e.g. FAO/UNESCO World Soil Map (1:5 M); FAO Soil Map for Europe (1:1 M); World Map of Salt Affected Soils (1:5 M); Global Assessment of Soil Degradation, GLASOD (1:5 M); SOVEUR (Soil Vulnerability Against Various Pollutants in Europe); EUSOPOL (European Soil Pollution); CTB ("Chemical Time Bomb" - time-delayed effect of various pollutants); Long-term Environmental Risks for Soils, Sediments and Groundwaters in the Danube Catchment Area; etc.

Soil Susceptibility/Vulnerability Maps

In the last years special attention has been paid to the characterization of soils from the viewpoint of their sensitivity/susceptibility/vulnerability against various natural and human-induced stresses. These researches consist of 3 steps:

(i) analysis of the mechanisms and influencing factors of the impact of various stresses;

(ii) elaboration of category sytems for the susceptibility classification of soils to various stresses, preferably with quantitative limit values;

(iii) the preparation of the map of these categories (using the data base of the above-mentioned soil maps and GIS facilities).

For practical application, the following steps are:

(iv) to prepare maps on the existing stress factors (e.g. atmospheric deposition; soil pollution; P load of surface waters; nitrate load of groundwaters, etc.);

(v) to prepare exceedance maps (comparing (ii) and (iv) indicating the ecologically sensitive, threatened or deteriorated "hot spots").

(vi) action plan to prevent, stop or moderate these environmental damages.

The following thematic soil susceptibility maps have been prepared during the last years (VÁRALLYAY, 1991):

(a) Susceptibility of soils to water and wind erosion (1:1 M) (STEFANOVITS, 1964; STEFANOVITS & VÁRALLYAY, 1992);

(b) Susceptibility of soils to acidification (1:500,000, 1:100,000) (VÁRALLYAY et al., 1993);

(c) Susceptibility of soils to salinization/alkalization (1:500,000) (SZABOLCS, DARAB & VÁRALLYAY, 1969);

(d) Susceptibility of soils to physical degradation, such as structure destruction, compaction and surface sealing (1:500,000) (VÁRALLYAY & LESZTÁK, 1990);
(e) Vulnerability of soils against various pollutants (under preparation).

Soil Information System

In the last years all existing soil data were organized into a computerized geographic soil information system (HunSIS = TIR), which is schematically illustrated in Figure 4 (CSILLAG et al., 1988; KUMMERT et al., 1989). TIR consists of two main parts:

(a) The *soil data bank,* including 3 different types of information:
  (i) basic topographic information (geodetic data standards and geographic reference systems);
  (ii) point information (measured, calculated, estimated or coded data on the various characteristics of soil profiles (or borings) or their different layers, diagnostic horizons (at present 35 soil and land characteristics), and
  (iii) territorial information (1:25,000 scale thematic maps on various physico-geographical factors (geomorphology, relief, groundwater conditions) and soil properties.

(b) The *information system,* including models on moisture and plant nutrient regimes of soils; susceptibility of soils to various soil degradation processes, such as water and wind erosion, acidification, salinization/alkalization, structure destruction and compaction; soil-water-plant relationships; status of soil pollutants and potentially toxic elements; etc.

The digitizer-computer-plotter distributed system, including adequate software is able to search for either location or attributes and display results in digital, tabular, graphical or cartographical form (data, categorized data, results of model calculations, thematic maps, etc.).

Current system development is focused upon the enhancement of local (i.e. workstation) modelling and editing functions, as well as to make this quadtree-based thematic GIS compatible with other gridded data sources.

The simultaneous application of (a) and (b) type inputs opens new output facilities: integrated data; classification and grouping of soil according to various criteria; interpreted results; practical recommendation for sustainable land use and proper soil management.

Soil Monitoring Systems

For the registration of soil changes three systematic monitoring systems were established:

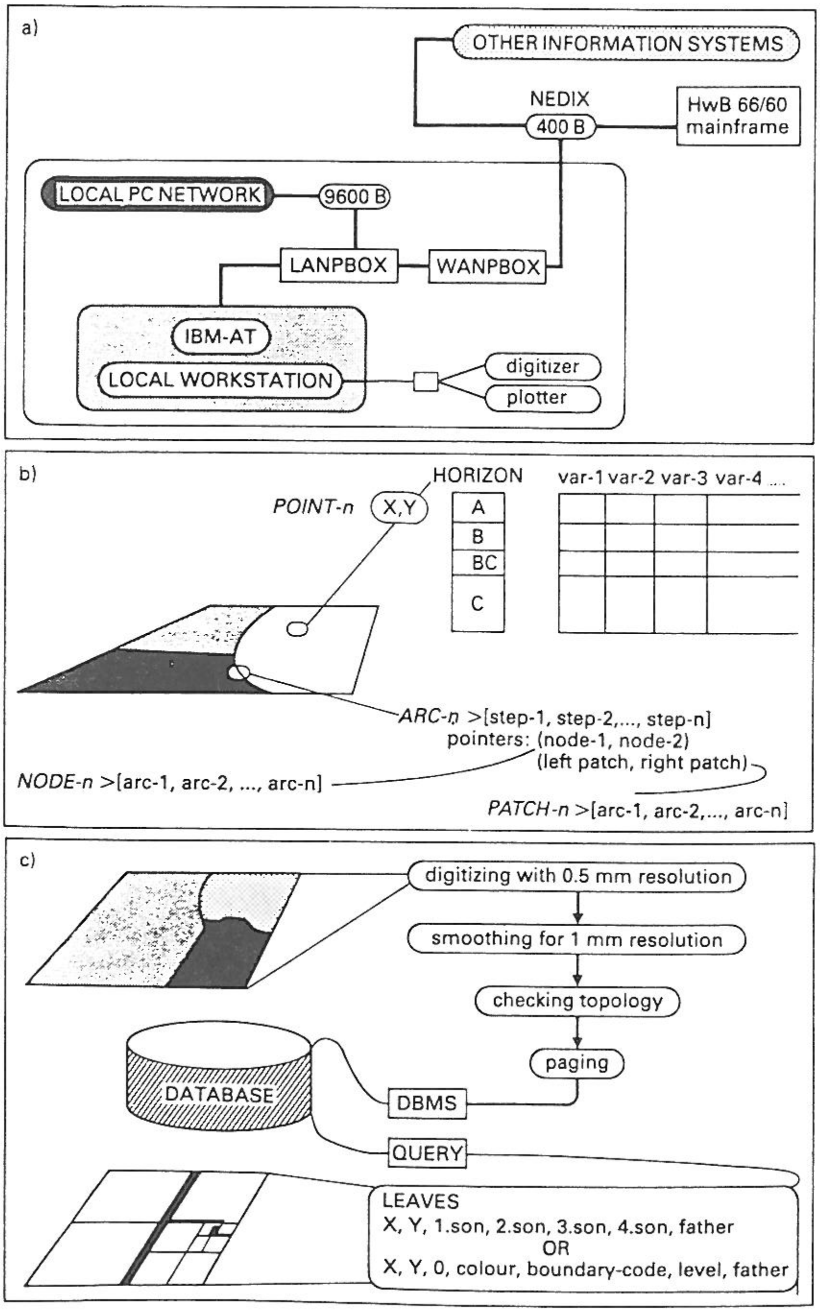

Figure 4
Hungarian Soil Information System (HunSIS = TIR). a) System scheme. b) Input data encoding. c) Map data flow from input via database to output

(a) *Soil fertility monitoring system (AIIR).*

In the system the most changeable soil characteristics (pH, $CaCO_3$ and organic matter content; saturation percentage (SP); total salt content; total and "mobile" N content; "available" P, K and Ca content; "soluble" Mg, S, Cu, Zn, Mn content) were measured in the topsoil (0-30 cm soil layer or the ploughed horizon; later in the 30-60 cm layer, as well) of about 100,000 agricultural fields covering near to 5 million hectares [the total agricultural area of the 93 thousand sq. km. Hungary is about 6.5 million hectares], in 3-year cycles. The programme started in 1978 (I.: 1978-1981; II.: 1982-1985; III.: 1986-1989) and stopped before completing the third cycle (BARANYAI, FEKETE & KOVÁCS, 1987).

The data were computer stored per agricultural field (their average size was about 50 hectares at that time), without inner contours of the maximum 12 hectares sampling sites, where mixed samples (composed from 30-30 "subsamples") were collected in two replicates for laboratory analysis.

In addition to the "soil properties file", separate files contain detailed information on the land-site characteristics (climate, relief, geology), on the agrotechnical operations (tillage, sowing, nutrient supply, pest control, etc.) and on crop yields, respectively for the registered fields.

(b) *Microelement survey.*

In this system - in addition to the above-mentioned basic soil parameters - the "total" (interpreted as a potential "pool") and "soluble" (interpreted as mobile and plant available /?/) content of 20 elements were determined in the 0-30, 30-60, 60-90 cm soil layers of 6,000 soil profiles, representing about 5 million hectares of agricultural fields.

The planned cycle was 3 years. The first sampling was in 1987-1988.

The programme stopped during the second cycle (because of financial limitations). The 6,000 "representative" sampling sites were selected by regional soil experts on the basis of available previous soil information and on their long-term local experiences.

1000 "representative" soil samples have been selected from the above-mentioned sample collection by national soil correlators for laboratory analysis. In the 1st cycle ("starting point" the following 20 elements were determined: Al, B, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Zn from 5 various extractants (by ICP): 0,1 *N* HNO_3; 0,02 *N* $CaCl_2$; NH_4-lactate-EDTA; $(NH_4)_2SO_4$; LAKERV.

On the basis of experts' data analysis of the results of the 1st cycle LAKERV was selected for the characterization of the status of these elements in soils.

On the basis of analytical data 1:2,000,000 scale thematic maps were prepared for Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb. On the map the measured data (classified into categories defined by limit values) are indicated with a 6x6 km grid) the sampling site is exactly defined by geographical coordinates and serves as the center-point of the grid (that is the reason why the grids sometimes overlap each other to a certain extent.

Soil Information and Monitoring System (TIM)

The new Soil Information and Monitoring System (TIM) is an independent subsystem of the integrated Environmental Information and Monitoring System (KIM) (VÁRALLYAY, 1993).

Based on physiographical-soil-ecological units 1200 "representative" observation points were selected (and exactly defined by geographical coordinates using GPS): 800 points on agricultural land, 200 points in forests and 200 points in environmentally threatened "hot spot" regions (representing 12 different types of environmental hazards or particularly sensitive areas, such as: degraded soils; ameliorated soils; drinking water supply areas; watersheds of important lakes and reservoires; protected areas with particularly sensitive ecosystems; "hot spots" of industrial, agricultural, urban and transport pollution; military fields; areas affected by (surface) mining; waste (water) disposal affected spots.

The "representative" sampling sites were selected by regional soil experts on the basis of all available soil information (profile descriptions, results of laboratory analysis, long-term field observations, maps, etc.) and on their local experiences. The forest and the "hot spot" sampling sites were selected in cooperation with regional forest land-site experts, environmentalists and experts of the given environmental hazards.

The sampling date is September 15 - October 15 each year. The first sampling was in 1992. In the monitoring system some soil parameters are measured every year, some others every 3 years or every 6 years - depending on their changeability (stability) (Table 3).

In addition to the existing soil maps and maps on the various physico-geographical factors new technics (geostatistical analysis, remote sensing, etc.) will be applied to extend point information into territorial ones (if it is necessary, possible and rational). The hardware-software configuration of the database guarantee the compatibility of TIM with the other subsystems of the integrated Environmental Information and Monitoring System (KIM), which is under elaboration now.

Multipurpose Applicability of Soil Information

Hungarian soil science, soil survey and soil testing practices always successfully serve the agricultural development, the planning and organization of crop production and environment control (Proceedings of the Hungarian-Swedish Seminar on Soil Mapping, 1989; VÁRALLYAY, 1989, 1993) as well as

Table 3
SOIL CHARACTERISTICS
determined in the basic observation points [I, M] of the soil information and monitoring system for environmental control TIM [HUNGARY]

Soil characteristics		at start t_0	yearly	3 yearly	6 yearly	Remarks
Morphological description of the soil profile		+				
Particle-size distribution		+				
Texture (SP)		+				
Hygroscopic moisture content (hy_1)		+				
Total water storage capacity (WC_T ~ pF_0)		+				on undis-turbed soil cores
Field capacity (FC ~ pF 2,5)		+				
Wilting percentage (WP ~ pF 4,2)		+				
Available moisture range (AMR = FC-WP)		+				
Saturated hydraulic conductivity		+				
$CaCO_3$ content	if > 5 %	+			+	
	if 1 - 5 %	+		+		
	if < 1 %	+	+			
$pH(H_2O)$	if $CaCO_3$ > 1 %	+		+		
	if $CaCO_3$ < 1 %	+	+			
pH(KCl)	if $CaCO_3$ > 1 %	+		+		
	if $CaCO_3$ < 1 %	+	+			
Hydr. acidity (y_1) if $CaCO_3$% = 0		+	+			
Exch. acidity (y_2) if $CaCO_3$% = 0		+	+			
Total water-soluble salts (in salt-affected soils (sas))		+	+			
1:5 water extract analysis [pH, EC; CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+] (in sas)		+			+	
Phenolphtalein alkalinity(in sas)		+		+		
Depth of the humus horizon		+			+	profile
Organic matter content		+	+			
CEC (cation exchange capacity)		+			+	
Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+, K^+)		+			+	
Total N		+		+		
NO_3-NO_2		+	+			
"Available" plant nutrients [P, K, Ca, Mg; NO_2-NO_3; Fe, Cu, Zn, S, Mn]		+		+		
Potentially toxic elements [Al, As, B, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Se, Sn, Sr, Zn]		+		+		
	"total"	+				
	"mobile"	+		+		
Cellulose-test	as indicators of soil "bio-logical" activ-ity	+		+		
Dehydrogenase activity		+		+		
CO_2 production		+		+		
Natural radioactivity		+		+		
"Average depth to the groundwater table		+	+			
Chemical composition of the groundwater [pH, EC, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, Ca^{2+}, Mg^{2+}, Na^+, K^+] [micronutrients] [micropollutants]		+	+			

the rational planning (site selection, territorial arrangement, etc.) and establishment of long-term field experiments and the multipurpose interpretation of their results.

The main fields of successful applications were as follows:

- control of limiting factors of soil fertility and soil degradation processes (water and wind erosion; acidification; salinization/alkalization; physical degradation of soil as structure destruction, compaction; biological degradation of soil; etc.);
- control of soil moisture regime;
- control of nutrient regime;
- control of soil and water pollution;
- control of other environmental hazards (e.g. landscape deterioration, etc.), biosphere preservation, including biodiversity, etc.

In the future soil monitoring will have sharply increasing significance in sustainable agricultural production (and its risk-reduction) harmonized with successful environment protection, ensuring pleasant life in a clean and nice environment.

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