# Mapping of Hydrophysical Properties and Moisture Regime of Soils

Gy. VÁRALLYAY

Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest

The primary task of agricultural water management is the regulation of the soil moisture regime, and by this way:
- to create optimum soil ecological environment for natural vegetation and cultivated crops;
- to maintain or increase soil fertility by favourably influencing soil processes;
- to ensure favourable soil technology conditions for the various agrotechnical operations

without any harmful side-effect /unfavourable human-induced changes/ on the natural environment.

The necessity and conditions of the various measures of agricultural water management are determined - beside the climatic conditions and the requirements of cultivated crops - by the hydrophysical properties and the moisture regime of soils. Their main factors are:
- the depth, thickness and sequence of various soil horizons /layers/ within the soil profile between the soil surface and the groundwater table;
- the hydrophysical characteristics of these soil layers;
- the quantity, status, energy relations, chemical composition; vertical and horizontal movement of soil moisture.

For the exact and accurate characterization of soil water management quantitative information are necessary on the above-mentioned parameters, as well as on their spatial /three-dimensional/ distribution and dynamism in time, on the influencing factors, their mechanisms and boundary conditions.

For the planning, realization /implementation/ and control of the various actions of agricultural water management, ameliorative and agrotechnical measures for soil moisture control adequate /exact, accurate, territorial/ soil information are required on the hydrophysical characteristics of soil, on their influencing factors and on the possibilities of their regulation. These information are necessary on each level and in all phases of these control actions. The four decision levels in Hungary can be characterized by the following scales:

- national level: 1:500 000
- regional level: 1:100 000
- farm level: 1:25 000-1:10 000
- agricultural field /plot level/: 1:10 000-1:5 000

} and adequate data base corresponding to these scales /number of parameters and their categories; limit values; "measurement density", etc./

In the last years a comprehensive soil information system /including soil survey, analysis, data management and interpretation, mapping, monitoring, modelling, prognosis/ was elaborated and successfully used in Hungary /VÁRALLYAY, 1987, 1988/ for the efficient control of soil moisture regime, which has particular significance in the country both in agricultural development and environment protection /VÁRALLYAY, 1988, 1989a, 1989b/. The system is valid /with high probability/ primarily to Hungarian conditions, but the conceptual basis, the system-approach and even the distinguished classes and their diagnostic characteristics and limit values can be properly used in other countries, as well. Some main elements of the system are summarized in the present paper.

*Category system and 1:100 000 scale map of hydrophysical properties of soils*

For regional soil moisture control a 1:100 000 scale map was prepared and a category system was elaborated on the hydrophysical properties of soils in Hungary /VÁRALLYAY, 1986; VÁRALLYAY et al., 1980/. The system is based on all available information: the previous works of SZABOLCS /cit in National Plan for Water Management, 1964/, DARAB /1962/; DARAB and FERENCZ /1969/ in Hungary; the international experiences /BOUMA, 1977, 1983; BOUMA et al., 1980/; and the results of Hungarian soil mapping /VÁRALLYAY, 1989c/.

Static categorization of a natural object /as soil/ is always aim-dependent and subjective, to a certain extent. There are no absolutely objective, generally valid and "constant forever" category systems in nature, and - consequently - in soil science. In spite of this fact, category systems are required for several practical purposes, e.g. for soil mapping, especially for the mapping of hydrophysical properties and moisture regime of soils. It can be properly done if the inadequacies and limitations, as well as the validity and applicability criteria of the given category system are known and it is not used over its exactly determined boundary conditions. Consequently, this category system /Information on the influencing factors...., 1982/ is applicable for medium-scale mapping and may serve as a soil scientific basis of regional planning.

In the system Hungarian soils were classified into nine main categories according to their hydrophysical properties and soil moisture constants. The nine main categories are, as follows:

(1) Soils with very high infiltration rate (IR), permeability (P) and hydraulic conductivity (HC); low field capacity (FC); and very poor water retention (WR).
(2) Soils with high IR, P and HC; medium FC; and poor WR.
(3) Soils with good IR, P and HC; good FC, and good WR.
(4) Soils with moderate IR, P and HC; high FC; and good WR.
(5) Soils with moderate IR, poor P and HC; high FC; and high WR.
(6) Soils with unfavourable water management: low IR, very low P and HC, and high WR.
(7) Soils with extremely unfavourable water management: very low IR, extremely low P and HC; and very high WR.
(8) Soils with good IR, P and HC, and very high FC.
(9) Soils with extreme moisture regime due to shallow depth.

The following quantitative parameters were given with their limit values for the nine soil water management categories:

(a) Field capacity (FC), as pF 2.5 } volume percentage = mm/10 cm soil layer
(b) Wilting percentage (WP), as pF 4.2 } volume percentage = mm/10 cm soil layer
(c) Available moisture range (AMR), as FC-WP
(d) Infiltration rate (IR), mm/hour, measured on the soil surface
(e) Saturated hydraulic conductivity (HC), cm/day /given for different layers./

In the case of soils classified into categories (1)-(5) the hydrophysical characteristics depend - besides soil compactness and structural state - primarily on texture. Therefore, in these categories saturation percentage (SP) and hygroscopic moisture content (hy) limit values were determined for the quantitative characterization of the textural class. FC, WP and AMR values are not given for the soils classified into categories (6) and (7), because their unfavourable water management and their extreme moisture regime are resulted mainly by their /very/ low IR and HC. In organic soils the AMR, IR and K-values have to be interpreted by a special way, therefore, no numerical characteristics are given for these parameters in category (8). In soils with shallow depth /category (9) / the moisture regime is determined primarily by the thickness of the productive soil layer and the water management of the soil is only moderately influenced by the physical properties of this horizon, consequently, the numerical limit values have been found unnecessary.

In many cases soil profiles are not uniform and there are great differences in the texture, physical and hydrophysical properties of the various soil horizons /layers/. To express vertical heterogeneity /three-dimensional character/ of soils and indicate it on a two-dimensional soil map is one of the main inadequacies and unsolved problems of soil mapping. This is the reason why in our category system subcategories were distinguished - within the (1)- (5) main categories - according to their soil profile variants, as follows:

(i) texture becomes lighter with depth /soils formed on relatively light textured parent material/: 2/1, 3/1;

(ii) uniform texture within the profile: 1/1, 2/2, 3/2, 4/2, 5/2;

(iii) relative clay accumulation in the horizon B: 4/1, 5/1.

Because the unfavourable moisture regime and the poor vertical drainage of the soils classified into category (6), is the consequence of a compact layer /with very low permeability and hydraulic conductivity/ within the soil profile, their profile-variants were distinguished according to the reason and the depth of this horizon, as follows:

6/1: heavy-textured soils with poor structure and a compact layer formed under the influence of misguided soil management;

6/2: pseudogleys;

6/3: deep meadow solonetzes, solonetzes turning into steppe formation /with an A-horizon thicker than 15 cm/ and solonetzic meadow soils;

6/4: soils with salinity/alkalinity in the deeper horizons.

The peaty meadow soils are also classified into this category as 6/5 variant.

No profile variants were established for the salt affected soils with extremely unfavourable water management /solonchaks, solonchak-solonetzes, meadow soils/ of category 7/1.

The profile variants for soils of categories (8) and (9) were established according to the texture of the parent material below the organic horizon and to the texture of the shallow soil profile above the limiting layer: solid rock, hardpans, cemented or over-compacted layers, gravel, coarse sand, peat, etc., respectively. The characteristic limit values of the categories and subcategories are summarized in Table 1 /VÁRALLYAY et al., 1980, 1982, 1983/.

On the basis of all available information /measured, calculated or estimated data, maps, etc./ the map of these categories and subcategories was prepared in the scale of 1:100 000 /The National Atlas of Hungary, 1989; VÁRALLYAY et al., 1980, 1982, 1983/. In many cases directly measured data were not available in adequate quantity /"density"/ for map construction, consequently, we used:

*Table 1*

Class limits for the categories and subcategories of hydrophysical soil properties

| Cate-gory | Vari-ants | Gene-tic hori-zon | Tex-tural class | FC | WP | AMR | IR | K | Territorial extension /in % of total area of Hungary/ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | mm/10 cm soil layer | | | mm/h | cm/d | | |
| 1. | 1/1 | 0-50 | s | <15 | <5 | 5-10 | >500 | >1000 | | |
| | | 50-100 | s | <15 | <5 | 5-10 | | 800-1000 | 10.5 | |
| | | 100-150 | s | <15 | <5 | 5-10 | | 500-800 | | |
| | | 150-200 | s | <15 | <5 | 5-10 | | 500-800 | | |
| 2. | 2/1 | a | sl | 15-25 | 5-10 | 10-15 | 300-500 | 500-1000 | | |
| | | b | ls | 10-20 | 4-8 | 6-12 | | 100-500 | 5.1 | |
| | | c | s | <15 | <5 | 5-10 | | 500-800 | | 10.8 |
| | 2/2 | a | sl | 15-25 | 5-10 | 10-15 | 150-300 | 500-1000 | | |
| | | b | sl | 15-25 | 5-10 | 10-15 | | 100-500 | 5.7 | |
| | | c | sl | 15-25 | 5-10 | 10-15 | | 300-600 | | |
| 3. | 3/1 | a | l | 25-35 | 10-20 | 15-22 | 120-150 | 10-20 | | |
| | | b | l | 25-35 | 10-20 | 15-22 | | 10-50 | 1.6 | |
| | | c | sl | 15-25 | 5-10 | 10-15 | | 100-500 | | 23.6 |
| | 3/2 | a | l | 25-35 | 10-20 | 15-22 | 100-300 | 10-100 | | |
| | | b | l | 25-35 | 10-20 | 15-22 | | 10-30 | 22.0 | |
| | | c | l | 25-35 | 10-20 | 15-22 | | 30-100 | | |
| 4. | 4/1 | A | l | 25-35 | 10-20 | 15-22 | 80-100 | 10-30 | | |
| | | B | cl | 35-42 | 20-27 | 12-17 | | 1-5 | 12.3 | |
| | | C | l | 25-35 | 10-20 | 15-22 | | 10-30 | | 18.1 |
| | 4/2 | a | cl | 35-42 | 20-27 | 12-17 | 70-100 | 1-10 | | |
| | | b | cl | 35-42 | 20-27 | 12-17 | | 3-7 | 5.8 | |
| | | c | cl | 35-42 | 20-27 | 12-17 | | 5-10 | | |
| 5. | 5/1 | A | cl | 35-42 | 20-27 | 12-17 | 60-70 | 1-5 | | |
| | | B | c | 42-50 | 27-35 | 10-15 | | 0.1-0.5 | 5.8 | |
| | | C | cl | 35-42 | 20-27 | 12-17 | | 0.5-2 | | 7.0 |
| | 5/2 | a | c | 42-50 | 27-35 | 10-15 | 50-70 | 0.1-1.0 | | |
| | | b | c | 42-50 | 27-35 | 10-15 | | 0.1-0.5 | 1.2 | |
| | | c | c | 42-50 | 27-35 | 10-15 | | 0.5-1.0 | | |
| 6. | 6/1 | a | c | 42-50 | 27-35 | 10-15 | 30-50 | 0.1-1.0 | | |
| | | b | c | 42-50 | 27-35 | 10-15 | | 0.05-0.25 | 3.2 | |
| | | c | c | 42-50 | 27-35 | 10-15 | | 0.1-0.5 | | |
| | 6/2 | A | | | | | 10-50 | 0.1-1.0 | | |
| | | B | | | | | | 0.01-0.1 | 1.8 | |
| | | C | | | | | | 0.1-0.5 | | |
| | 6/3 | A | | | | | 10-50 | 0.1-1.0 | | 16.4 |
| | | B | | | | | | 0.01-0.1 | 4.9 | |
| | | C | | | | | | 0.1-0.5 | | |
| | 6/4 | a | | | | | 10-50 | 0.5-1.0 | | |
| | | b | | | | | | 0.1-0.5 | 4.5 | |
| | | c | | | | | | 0.01-0.1 | | |

*Table 1 continued*

| Cate-gory | Vari-ants | Gene-tic hori-zon | Tex-tural class | FC | WP | AMR | IR | K | Territorial extension /in % of total area of Hungary/ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | mm/10 cm soil layer | | | mm/h | cm/d | |
| | 6/5 | a | o | >50 | >35 | | 10-50 | | |
| | | b | o | >50 | >35 | | | | 2.0 |
| | | c | l,cl | 30-40 | 15-25 | 15-20 | | 1-10 | |
| 7. | 7/1 | A | | | | | <10 | 0.01-0.1 | |
| | | B | | | | | | <0.01 | 3.6 |
| | | C | | | | | | 0.01-0.05 | |
| 8. | 8/1 | a | o | >50 | >35 | | | | |
| | | c | l | 25-35 | 10-20 | | | | |
| | | c | cl | 35-42 | 20-27 | | | | 1.4 |
| | | c | c | 42-50 | 27-35 | | | | |
| 9. | 9/1 | a/+b/ | l | 25-35 | 10-20 | 15-22 | | 10-100 | |
| | | | cl | 35-42 | 20-27 | 12-17 | | 1-10 | |
| | | | c | 42-50 | 27-35 | 10-15 | | 0.1-1.0 | 8.6 |
| | | | o | >50 | >35 | | | | |
| | | | | | | | | | 100.0 |

*Remarks:* a,b,c = profiles without or not significant texture differentiation; A,B,C = profiles with significant texture differentiation; s = sand; ls = loamy sand; sl = sandy loam; l = loam; cl = clay loam; c = clay; hc = heavy clay; o = partly decomposed peat; p = peat; g = coarse fragments.

- calculated /or estimated/ soil moisture constants, e.g. FC, WP and AMR values derived from water retention curves, calculated on the basis of measured particle-size distribution and bulk density /RAJKAI, 1987-1988/;
- soil taxonomy units /soil type, subtype, local variant - according to the Hungarian soil classification system/ as the "carrier" of physical-hydrophysical characteristics, knowing /or at least assuming/ the relationships between the hydrophysical characteristics and other soil properties, expressed by the /low/ taxonomy units.

The direct basis of the map was the 1:100 000 scale map of soil factors determining the agro-ecological potential of Hungary, indicating seven soil characteristics: soil type and subtype; parent material; reaction and carbonate status; texture; hydrophysical properties; organic matter content; depth of the soil /VÁRALLYAY et al., 1980, 1985/. Some of the thematic maps of these characteristics were presented in an other paper of this issue /VÁRALLYAY, 1989c/. In Fig. 1 the thematic map of soil texture is shown, because - as it was already mentioned - soil moisture constants are closely related to soil texture, especially in categories (1) - (5). The simplified version of the 1:100 000 scale map of hydrophysical soil properties is presented in Fig. 2.

The area of each polygon delineated and indicated on the original map was determined and the plot-list was computer-stored. The territorial data of the map were summarized in three tables:


*Fig. 1*
Map of soil texture. /Simplified, schematic version of the original 1:100 000 scale map/. 1: sand; 2: sandy loam; 3: loam; 4: clay loam; 5: clay; 6: organic soils /peat, partly decomposed peat/; 7: coarse fragments /gravel, non- or partly weathered rocks, etc./

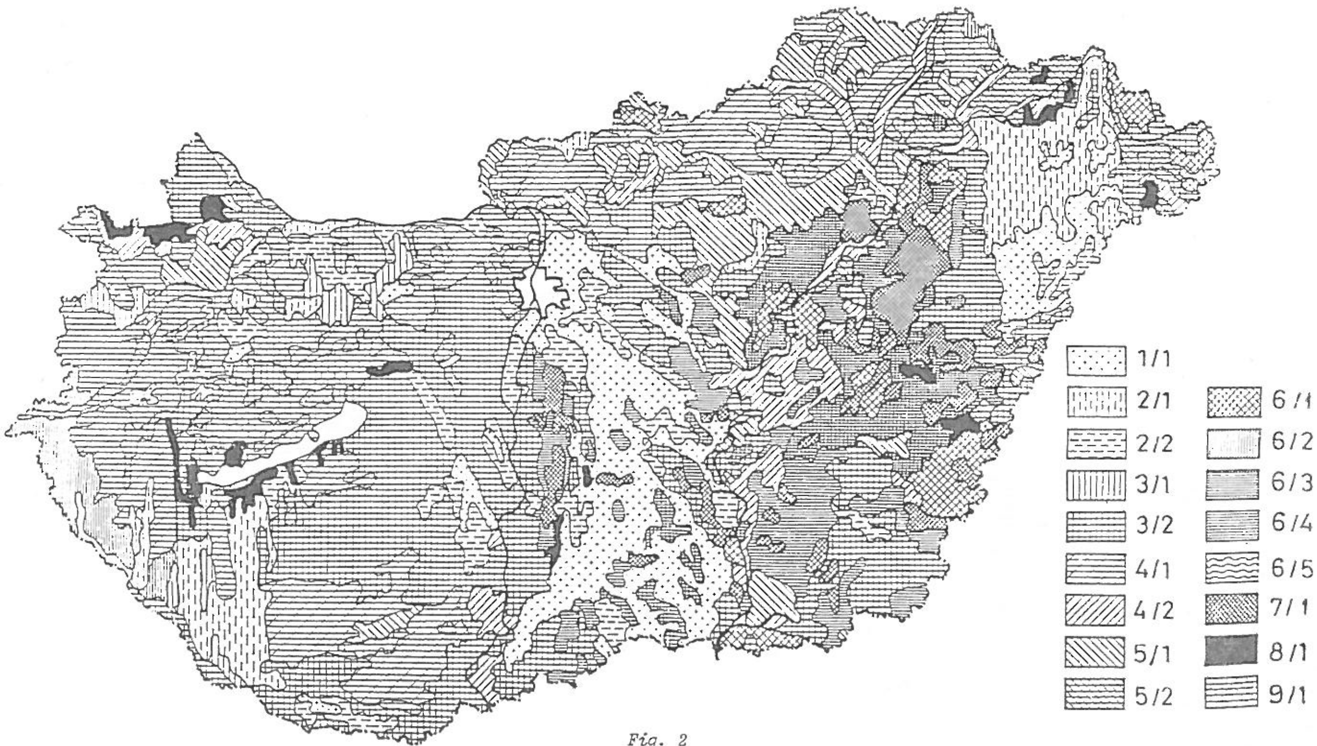


*Fig. 2*

Map of the hydrophysical properties of soils. /Simplified, schematic version of the original 1:100 000 scale map/. 1: soils with very high infiltration rate (IR), permeability (P), and hydraulic conductivity (HC), low field capacity (FC), and very poor water retention (WR); 2: Soils with high IR, P and HC, medium FC and poor WR; 3: Soils with good IR, P and HC, good FC, and good WR; 4: soils with moderate IR, P and HC, high FC, and good WR; 5. Soils with moderate IR, poor P and HC, high FC, and high WR; 6: Soils with unfavourable water management, low IR, very low P and HC, and very high WR; 8: Soils with good IR, P and HC and very high FC; 9: Soils with extreme moisture regime due to shallow depth. 1/1, 2/2, 3/2, 4/2, 5/2: uniform texture within the soil profile; 2/1, 3/1: texture becomes lighter with depth /soils formed on relatively light textured parent material/; 4/1, 5/1: clay accumulation in the B horizon; 6/1: extremely heavy-textured soils with poor structure and a compact layer formed under the influence of improper soil management; 6/2: pseudogleys; 6/3: deep meadow solonetzes, solonetzes turning into steppe formation, and solonetzic meadow soils; 6/4: soils with salinity/alkalinity in the deeper horizons; 6/5: peaty meadow soils

- distribution of the soil water management categories in the 19 counties /administrative regions/ of Hungary;
- distribution of the soil water management categories in the 35 agro-ecological regions of Hungary;
- distribution of the soil water management categories according to the 31 soil /sub/types of Hungary.

On the basis of the map, the computer-stored plot-list and the territorial data, selecting the adequate profile variant and calculation with the real thicknesses of the various a-b-c /profiles without or not significant texture differentiation/ or A-B-C /profiles with significant texture differentiation/ horizons the FC, WP and AMR values can be exactly and quantitatively determined for the various layers, or for the different profiles of any Hungarian soil.

These data represent a comprehensive basis for the exact and quantitative characterization of the water management of a soil type, subtype, variant; or a physico-geographical, administrative, farming or mapping unit /e.g. ecological region, watershed, water catchment area; county, administrative district; farm; agricultural field; etc./ and, consequently, for the regional optimation of soil moisture regime.

*1:500 000 map of the main moisture regime types of Hungarian soils*

Moisture regime has particular significance in the soil processes determining soil fertility. In Hungary most of the limiting factors of soil fertility and harmful soil degradation processes are related /are causes or consequences/ of unfavourable soil moisture regime.

The main components of the field water balance of a territory and a soil profile are summarized in Fig. 3. The simplified territorial water balance can be written as follows /For symbols see Fig. 3/:

$$\Delta S = [P + I + R_i + U_i + G_i] - [IN + T + E + R_o + U_o + G_o] \qquad /1/$$

The quantity of moisture stored in the unsaturated zone of the soil profile /S/ can be expressed as:

$$\Delta S = [F_S + U_i + C] - [F_G + U_o + A + E] \qquad /2/$$

The rise of the water table ($G_r$) increases, while the sinking of the water table ($G_s$) decreases the quantity of water that can enter the soil profile from the groundwater by capillary transport (C). The depth of the groundwater table is determined by the resultant of ($G_i + F_G$) and ($G_o + C$).

According to the character of their water balance, its main determining, dominating and influencing components, as well as on the detailed analysis of their effects on the mass and energy regimes of soils and their consequences on the soil formation and soil degradation processes, Hungarian soils were classified into 11 categories /VÁRALLYAY, 1985/. The moisture regime types are as follows:

(1) Heavy surface runoff.
(2) Heavy downward flow.
(3) Moderate downward flow.
(4) Equilibrium type.
(5) "Filtration" type.
(6) Upward flow /groundwater-wetted type/.
(7) Extreme moisture regime due to salinity-alkalinity.

(8) Extreme moisture regime due to shallow depth.
(9) Moisture regime under the influence of surface water streams.
(10) Regular waterlogging.
(11) Forests with special moisture regime.

The dominant character, the main /determining/ components and the physico-geographical and soil conditions of the 11 moisture regime types in Hungary are summarized in Table 2.

Based on all available territorial information on the factors of the field water balance /climatic factors, surface runoff, groundwater conditions, etc./ /National Plan for Water Management, 1964; Information on the influencing...., 1982/ the map of the main types of soil moisture regime was prepared on the scale of 1:500 000 /VÁRALLYAY, 1985/. The simplified version of this map is shown in Fig. 4.

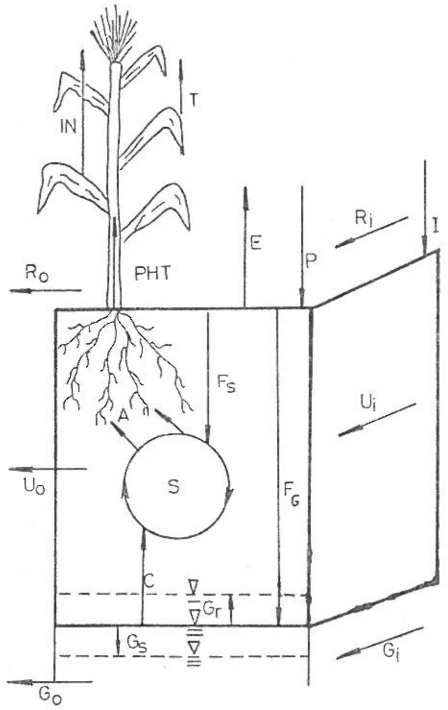


*Fig. 3*

Factors of soil moisture regime. PHT: physiological water transport within the plant; S: water storage within the soil; P: atmospheric precipitation; I: quantity of irrigation water; IN: interception /direct evaporation from the leaf surfaces/; $R_i$: surface runoff into the area; $R_o$: surface runoff away from the area; $U_i$: filtration within the unsaturated zone into the area; $U_o$: filtration within the unsaturated zone away from the area; $G_i$: groundwater flow into the area; $G_o$: groundwater flow away from the area; E: evaporation; T: transpiration

*Table 2*

Characteristics of the main types of soil moisture regime in Hungary

| No. | Type | Type of moisture regime: Water balance: character | main /determining/ components | Physico-geographical and soil conditions |
|---|---|---|---|---|
| /1/ | Heavy surface runoff | Ø | $R_i$, $R_o$ | Relief; vegetation cover; precipitation |
| /2/ | Heavy downward flow | + | $F_s$ | High precipitation, low groundwater-table |
| /3/ | Moderate downward flow | /+/ | $F_s$ | Moderately high precipitation, low groundwater table |
| /4/ | Equilibrium type | = | $F_s$; E, T | Low precipitation, low groundwater table |
| /5/ | "Filtration" type | /+/ Ø | $F_B$ /$F_s$/ | Highly permeable soil, low groundwater table |
| /6/ | Upward flow /groundwater-wetted type/ | – | C, G | High, non-stagnant groundwater with low salinity |
| /7/ | Extreme moisture regime due to salinity-alkalinity | – | C, G | High "stagnant" saline groundwater |
| /8/ | Extreme moisture regime due to shallow depth | Ø | Ø | Solid rock, compact or cemented layer near to the surface, limiting infiltration and root penetration |
| /9/ | Moisture regime is under the influence of surface water streams | Ø | $R_i$ | Periodical flooding and alluvium deposition |
| /10/ | Regularly waterlogged areas | + | $R_i$, $G_i$ | Regular waterlogging |
| /11/ | Forests with special moisture regime | Ø | IN, T | |

Remarks: Ø: no significance; –: negative balance; +: positive balance; /+/: moderately positive balance; =: equilibrium.

*Large-scale mapping of hydrophysical properties and moisture regime of soils*

In the planning, implementation and follow-up /control, maintenance/ of various actions for an efficient soil moisture control on farm and field level more detailed information are required on the hydrophysical properties and moisture regime characteristics of the soil. For this purpose a comprehensive survey-analysis-data processing, evaluation, interpretation-mapping-

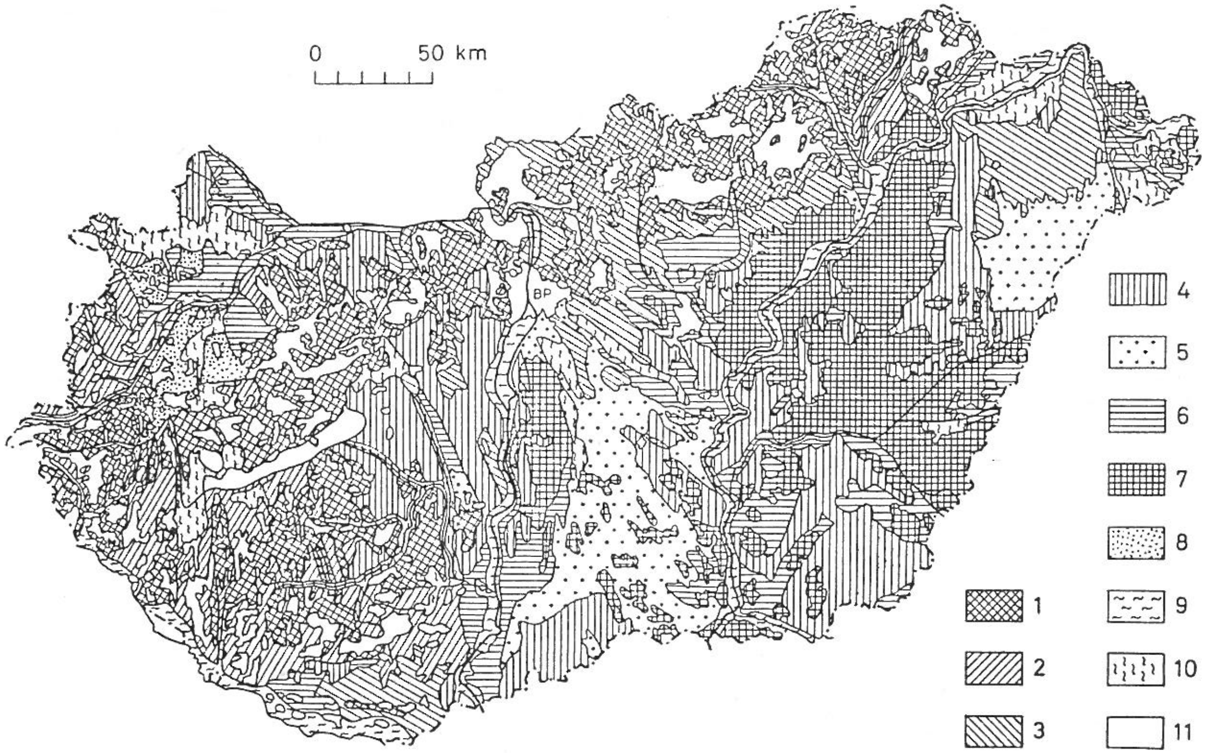


*Fig. 4*

Map of the main moisture regime types of Hungarian soils. /Simplified, schematic version of the original 1:500 000 scale map/. 1: Heavy surface runoff; 2: Heavy downward flow; 3: Moderate downward flow; 4: Equilibrium-type; 5: Rapid filtration type /light-textured soils/; 6: Groundwater-wetted type /upward flow is dominant/; 7: Extreme moisture regime due to unfavourable hydrophysical soil properties; 8: Extreme moisture regime due to shallow depth; 9: Soils under the influence of rivers and surface streams; 10: Regularly waterlogged areas; 11: Forest with special moisture regime

-monitoring-modelling-prognosis system was developed and successfully used in Hungary /VÁRALLYAY, 1987, 1989b/.

The system consists of the preparation of four thematic maps in large /1:10 000-1:25 000/ scale with the application of a digital code system, in which the various categories are defined by the limit values of various measured or calculated soil and groundwater characteristics, as follows:

1. The soil map indicates general soil characteristics, as soil type, subtype and main local variants /altogether 250 categories - expressed by the first three digits of the code; soil reaction - 9; carbonate status - 10; texture - 10; depth of the humus horizon - 7; organic matter content - 8; soil depth - 7 categories, respectively.

2. The map of salinity-alkalinity status shows the average total water soluble salt content - 8; maximum total water soluble salt content - 6; depth of the maximum salt content within the soil profile - 6; thickness of the A horizon - 5; ESP in the A horizon - 5; pH in the $B_1$ horizon - 4; ESP in the $B_1$-horizon - 5; characteristic cation composition - 7; characteristic anion composition - 7 categories, respectively.

3. The map of hydrophysical properties, indicates the textural classes - 10 categories; bulk density - 5; total porosity, maximum water capacity as pF 0 - 7; field capacity as pF 2.5 - 10; wilting percentage as pF 4.2 - 10; available moisture range as the difference of pF 2.5 and pF 4.2 - 8; saturated hydraulic conductivity - 10; quantity of water entering the soil profile from the groundwater table to the overlying soil horizons by capillary transport - 6; stratification /layering/ of the soil profile /using a special code system for it/ - 10; average depth to the water table - 7 categories, respectively. The category matrix of this map /containing the limit values for these categories/ is shown in Table 3 - as an example.

4. The map of groundwater conditions expresses the average, minimum and maximum depth of the groundwater table below the surface - 7-7; average salt content - 6; cation composition - 7; anion composition - 7; sodium percentage and SAR /sodium adsorption ratio/ of the groundwater - 7 categories, respectively.

The main data sources of the large-scale maps are field survey information; data of field measurements and laboratory analysis; remotely-sensed data /aerial photographs; multispectral, infrared, or false-color satellite imagery; radar and microwave observations/; calculations and estimations on the basis of verified models expressing some existing relationships: e.g. calculation of water retention /pF/ curves on the basis of measured data of particle-size distribution, saturation percentage /SP/, bulk density, organic matter content and salinity-alkalinity status /RAJKAI, 1987-1988/, etc.

The most problematic point of the large-scale mapping of hydrophysical soil properties, however, is the extension of point information /data for soil profiles or their horizons/ into territorial /or even 3 or 4 dimensional - including time factor/ information /VÁRALLYAY, 1989c/. For this purpose remote sensing, the application of up-to-date geostatistical procedures and computer techniques are promising new tools, but will never solve the problem alone, without "human co-operation".

Two other problems were discussed earlier:

- to what extent can we use soil mapping units /or even soil taxonomy units/ as the "carrier" of soil information, in this case hydrophysical properties and soil moisture characteristics;
- categorization of soil properties /possibilities, realities, subjectivity, limitations/.

*Table 3*

Category matrix of the large scale map of hydrophysical soil properties

| Code No. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. |
|---|---|---|---|---|---|---|---|---|---|---|
| Category | Textural class of the topsoil | Bulk density $g/cm^3$ | pF 0 vol % total porosity, $P_t$; total water capacity /$WC_t$/ | pF 2.5 vol.% field capacity, FC | pF 4.2 vol.% wilting percentage, WP | Available moisture range, AMR, vol. % | Saturated hydraulic conductivity, K, cm/day | Capillary transport from the groundwater, mm/year | Layer-sequence code | Average depth to the water table, m |
| 1 | s | < 1,0 | < 35 | < 10 | < 2 | < 2 | < 0,01 | 0 | = | < 0.5 |
| 2 | ls | 1,0–1,2 | 35–40 | 10–15 | 2–5 | 2–5 | 0,01–0,1 | < 50 | − 2 | 0,5–1 |
| 3 | sl | 1,2–1,4 | 40–45 | 15–20 | 5–10 | 5–10 | 0,1–0,5 | 50–100 | > − 2 | 1–2 |
| 4 | l | 1,4–1,6 | 45–50 | 20–25 | 10–15 | 10–15 | 0,5–1 | 100–150 | + 2 | 2–3 |
| 5 | cl | > 1,6 | 50–55 | 25–30 | 15–20 | 15–20 | 1–5 | 150–200 | > + 2 | 3–4 |
| 6 | c | | 55–60 | 30–35 | 20–25 | 20–25 | 5–10 | > 200 | − k | 4–6 |
| 7 | hc | | > 60 | 35–40 | 25–30 | 25–30 | 10–50 | | + k | > 6 |
| 8 | o | | | 40–45 | 30–35 | > 30 | 50–100 | | + K | |
| 9 | p | | | 45–50 | 35–40 | | 100–500 | | c | |
| 10 | g | | | > 50 | > 40 | | > 500 | | r | |

s = sand
ls = loamy sand
sl = sandy loam
l = loam
cl = clay loam
c = clay
hc = heavy clay
o = partly decomposed peat
p = peat
g = coarse fragments

Layer sequence code:

| | | |
|---|---|---|
| 1 | = | homogeneous soil profile |
| 2 | −2 | texture becomes moderately lighter with depth |
| 3 | >−2 | texture becomes strongly lighter with depth |
| 4 | +2 | texture becomes moderately heavier with depth |
| 5 | >+2 | texture becomes strongly heavier with depth |
| 6 | −k | interstratified lighter horizon |
| 7 | +k | interstratified moderately heavier horizon |
| 8 | +K | interstratified strongly heavier horizon |
| 9 | c | compact or cemented layer within the soil profile |
| 10 | r | stratified /multilayer/ soil profile |

*Practical application*

The maps and their territorial data give information on the soil factors of the field water cycle: the quantity of water that runs off from sloping terrains /and results in soil erosion processes/ directly evaporates from the surface; filtrates into the soil; percolates through the soil profile and feeds the groundwater; stored within the soil and available for plants, etc. Conclusions may be drawn on the frequency, probability and potential factors of both extremes of the moisture regime /waterlogging, overmoistening - drought sensitivity/, and their physiological and agronomical consequences /non-adequate water-supply of plants, yield depressions; problems of mechanized agrotechnical operations: increasing energy consumption, inadequacies in their quality, soil deteriorations as structure destruction and compaction, etc./.

Some Hungarian results in this respect can be summarized, as follows:

(a) A 1:100 000 scale map was prepared on the soil factors of waterlogging and overmoistening in Hungary /indicating the reasons and the practical possibilities of their prevention, elimination or moderation/.

(b) A 1:100 000 scale map was compiled on the susceptibility of Hungarian soils to physical degradation: structure destruction and compaction /VÁRALLYAY and LESZTÁK, 1989/. The simplified version of this map is shown in Fig. 5.

(c) A five-step model system was established /VÁRALLYAY, 1987/ for the exact and quantitative characterization of moisture flow and solute transport within layered soil profiles above a fluctuating groundwater table; and for the estimation of the quantity of water and soluble constituents entering the soil profile from the groundwater by capillary transport. All the soil and groundwater data required for the model are indicated on large-scale maps, mentioned above.
The model can be used for the determination of the "optimum depth" /ensuring additional moisture supply for plants from the good-quality groundwater/ and the "critical depth" /preventing salt accumulation, salinization-alkalization from saline, poor-quality groundwater/ of the water table /VÁRALLYAY, 1987/.
The model system was successfully applied in practice, during the planning and establishment of the Dunakiliti-Gabcikovo /Danube Plain, NW-Hungary and SW-Slovakia/ and the Kisköre /Tisza Plain, E-Hungary/ Irrigation System /SZABOLCS et al., 1969/, respectively.

(d) The maps and their data base were inputs to the computerized geographical soil information system of Hungary.

On the basis of these information the necessity and possibilities of the theoretical, real, rational and economical soil moisture regulation can be determined, the probable efficiency of the various actions can be forecasted, and proper technologies can be elaborated for the optimum variants. The maps and their data base represent adequate soil information for the establishment of optimum /or nearly optimum/ soil water management and for the elaboration and application of proper, rational and efficient measures for soil moisture control. An example is given in Table 4 where soil characteristics are summarized, required for the planning of various ameliorative measures, including measures for soil moisture control /VÁRALLYAY, 1989a/.

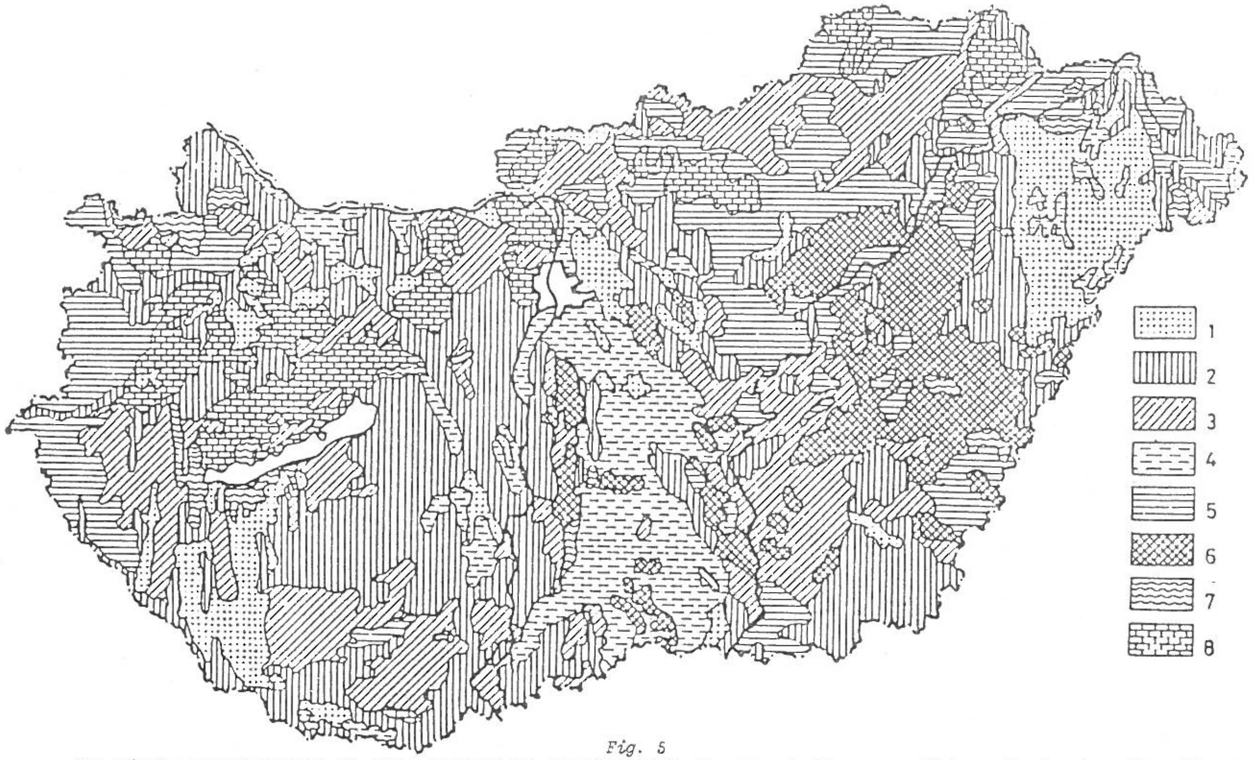


*Fig. 5*

Map of the susceptibility of soils to physical degradation in Hungary. 1: Non-susceptible soils /sandy soils without structure and with a low content of cementing compounds as carbonates or sesquioxides/; 2: Slightly susceptible soils /medium-textured soils with well-developed structure and high aggregate stability/; 3: Moderately susceptible soils /medium-textured soils with moderately developed structure and low aggregate stability/; 4: Soils susceptible to compaction and surface crusting but not to structure destruction /sandy soils without structure but high amount of cementing compounds, mainly carbonates/; 5: Soils susceptible to structure destruction and compaction /heavy textured soils of swelling-shrinkage character and low structural stability/; 6: Soils susceptible to both structure destruction and compaction due to salinity-alkalinity; 7: Organic soils /peats/; 8: Shallow soils /solid rock or cemented layer near the surface/

*Table 4*

SOIL CHARACTERISTICS REQUIRED FOR THE PLANNING OF VARIOUS AMELIORATIVE MEASURES

| Type of amelioration / Soil /landsite/ characteristics | Land levelling | Lime requirement | Reclamation of salt affected soils | | | Reclamation of sandy soils | | Deep loosening | | Amelioration of peats | Terracing | Drainage | | | | | | Surface drainage | Irrigation | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Elements | Ameliorativ agent | Required quantity | Elements | Ameliorativ agent and required quantity | Depth | Frequency | | | Necessity | Type | Drain spacing | Drain diameter | Drain slope | Filtering | | Necessity | Scheduling | Quantity of water required | Quantity of water can be applied | Frequency | Intensity of irrigation | Method |
| Microrelief | + | | | | | + | | | | | + | + | + | + | | + | | + | | | | | | + | + |
| Soil type, subtype, variant | + | + | + | | | + | | | + | + | + | + | + | | | | | | | | | | | | |
| Layering | + | + | + | + | + | + | + | + | | + | + | + | + | + | | + | | + | + | + | + | | + | + | + |
| pH | | + | + | + | + | + | + | | | | | | | | | | + | + | | | | | | | |
| Parameters of soil acidity $/y_1y_2/$ | | + | | | | + | + | | | | | | | | | | + | | | | | | | | |
| Parameters of soil alkalinity | | | + | + | + | | | | | | | | | | | | | | | | + | | | | |
| $CaCO_3$ content of the topsoil,% | | | | + | | + | + | | | | | | | | | | | | | | | | | | |
| $CaCO_3$ profile, %-cm | + | + | | + | | + | + | + | | + | | | | | | | | | | | | | | | |
| Average content of water soluble salts, % | | | + | + | + | | | | | | | + | + | | | | | + | | | + | | | | |
| Salt profile, %-cm | + | | + | + | + | | | + | | + | | + | + | | | | | + | | | + | | | | |
| Salt composition | | | + | + | + | | | | | | | + | | | | | | + | | | + | | | | |
| Exchangeable $Na^+$ content % /LSP/ and meq/100 g soil | | | + | + | + | | | | | | | | | | | | | + | | | + | | | + | |
| Cation exchange capacity, CEC meq/100 g soil | | + | | | + | + | + | | | | | | | | | | | | | | | | | | |
| Textural class /particle-size distribution, SP, $hy_1$/ | + | + | + | | + | + | + | + | + | + | + | + | + | + | | + | + | + | + | | + | + | + | + | + |
| Bulk density, $g/cm^3$ | | | | | | + | | + | + | | + | | | + | | | + | + | | | + | | + | + | + |
| Total water capacity, $WC_T$ as pF 0 | | | | | | | | | | | | + | + | + | + | + | | + | | | + | | + | | + |
| Field water capacity, $WC_T$ as pF 2,5 | | | | | | | | | | | | + | + | + | + | + | | | + | + | + | + | + | | + |
| Wilting percentage vol.% as pF 4.2 | | | | | | | | | | | | | | | | | | | + | + | | + | + | | + |
| Available moisture range, as FC-WP | | | | | | | | | | | | | | | + | + | | | + | + | | + | + | | + |
| Depth of wetting, cm | | | | | | | | | | | | + | + | + | + | + | | + | + | | + | + | + | | + |
| Infiltration rate, IR, cm/hour | | | | | | | | | | | | | + | | + | + | | + | | | | | | + | + |
| Saturated hydraulic conductivity, K, cm/day | | | | | | | | | | | | | + | + | + | + | + | + | | | | | | + | + |
| Unsaturated capillary conductivity, k- cm/day | | | | | | | | | | | | | | | | | | | + | + | | + | + | | |
| Moisture content, vol.% | | | | | | | | | | | | + | | | + | + | + | + | + | + | + | + | + | | + |
| Fe-content, ppm | | | | | | | | | | | | | | | + | + | + | | | | | | | | |
| Depth of water table, cm | | | + | | | | | | | + | | + | + | + | + | | | + | + | | + | + | + | | + |
| Horizontal flow of groundwater | | | + | | | | | | | + | | + | + | + | + | + | | | | | | | | | |
| Salt concentration and ion composition of the groundwater | | | + | | | | | | | + | | + | + | + | | | + | | + | | | + | + | | + |
| Salt concentration and ion composition of the irrig.water | | | + | | | | | | | | | | | | | | | | | | | | | | |

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