# Soil Water Problems in Hungary

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The basic aim of agriculture is the economical production of crops of good quality in maximum quantity with minimum input and without any harmful side-effects, i.e. unfavourable, non-, hardly-, expensively or non-economically correctable changes in the environment, in the soil-, water- and biological resources, landscape, etc. in the given area and its surroundings; at the present time, or in the near and far future.

*Soils* are the most significant - conditionally renewable/!/ - natural resources and the basic means of agricultural production. Soil as reactor, transformator and integrator of other natural resources /solar radiation; atmosphere; surface and subsurface waters; biological resources/ is the "life media" for microbial activities and the ecological environment of natural vegetation and cultivated crops. Soil is a high capacity buffer media of the biosphere, which may buffer or can moderate various stresses, caused by environmental factors and/or human activities. Soils represent a considerable part of the natural resources in Hungary, consequently, their rational utilization and conservation have particular importance in the national economy and in environment protection, respectively /VÁRALLYAY, 1987/.

*Water* as solvent, reactant and transporting agent plays an important /sometimes decisive/ role in physical and chemical weathering, soil formation and soil degradation processes /abiotic and biotic transport and transformation phenomena/, and water is an indispensable factor of life on Earth.

*Soil water - soil fertility*

The most important characteristic of soil is fertility, the specific feature that water, air and plant nutrients may occur simultaneously in this four-dimensional, four-phase /solid-liquid-gaseous-biological/ polydisperse system and may cover - to a certain extent - the water and nutrient requirements of plants. Soil fertility depends on the integrated influence of various soil properties, which are the result of the mass and energy regimes, abiotic and biotic transport and transformation processes. Consequently, any soil-related activity influences soil fertility through the modification of these processes.

Soil moisture regime determines the ratios among solid, liquid and gaseous phases. Thus, it influences the air regime /aeration, gas exchange/, heat regime, biological activity and plant nutrient status /resources, transport and transformation, mobility and availability for plants/. The quantity, state and movement of soil moisture determine not only the water supply of plants, but regulate their nutrient uptake and metabolism, as well as the hazards of "nutrient pollution" of surface and subsurface waters. Consequently, soil moisture regime has particular significance among soil ecological factors strongly influencing /sometimes determining/ the ecological potential and agricultural productivity of a given area, the biomass production of various natural and agricultural ecosystems. Moisture regime influences soil technological characteristics /consistency, plasticity, stickiness, compactibility, penetrability, workability, trafficability, etc./, determines the possibilities of mechanized agrotechnical measures /especially soil tillage operations/ with minimum energy consumption and proper quality. These relationships are summarized in Fig. 1.

It is well-known, that:

- the major limitations of agricultural production on the World /drought; mineral stresses; shallow depth of the soil; water excess; permafrost/;
- the main limiting factors of soil fertility in Hungary /extremely coarse or heavy texture; high acidity; salinity-alkalinity; shallow depth; waterlogging; unfavourable biological activities and plant nutrient regime/ /SZABOLCS and VÁRALLYAY, 1978/;
- the most important soil degradation processes due to natural factors and/or human activities /water and wind erosion; solifluction; acidification; salinization-alkalization; physical degradations: structure destruction, ag-

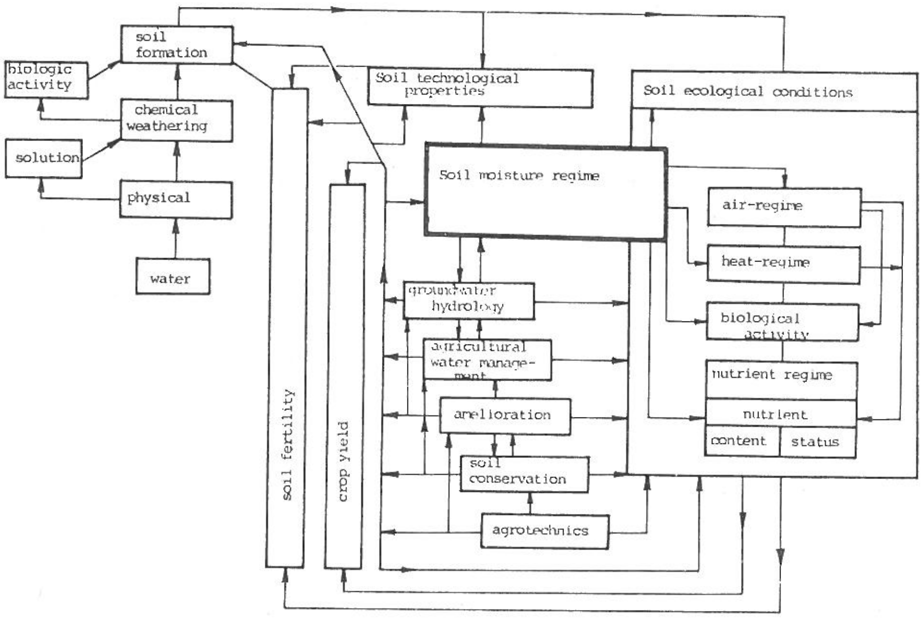


*Fig. 1*
The influence of soil moisture regime on soil fertility and possibilities of its regulation

gregate failure, compaction, surface sealing; biological degradation; leaching and immobilization of plant nutrients; pollution by toxic elements/ /VÁRALLYAY, 1989b/
are connected, are reasons or consequences of soil moisture regime. Consequently, most of the actions for the regulation /maintenance or increase/ of soil fertility are related to the control of soil moisture regime.

As an example for the above mentioned relationships, the distribution of Hungarian soils according to their hydrophysical properties and moisture

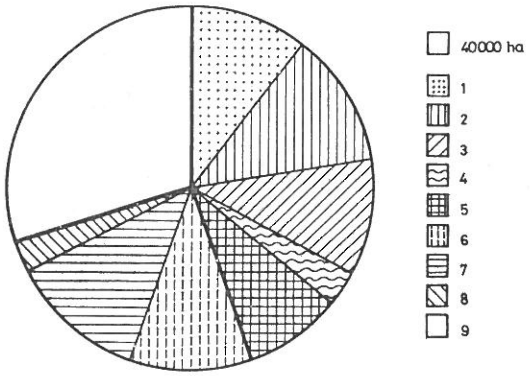


*Fig. 2*

Distribution of soils with good, moderate and unfavourable hydrophysical properties in Hungary. 1-5 = Soils with unfavourable hydrophysical properties: 1: due to very coarse texture; 2: due to very heavy texture; 3: due to strong salinity-alkalinity; 4: due to peat formation; 5: due to shallow depth; 6-8 = Soils with moderately unfavourable hydrophysical properties: 6: due to coarse texture; 7: due to heavy texture; 8: due to moderate salinity/alkalinity in the deeper layers; 9= Soils with good hydrophysical properties

characteristics is shown in Fig. 2, indicating their soil limitations. As it can be seen in the Figure, 43% of the soils have unfavourable hydrophysical characteristics due to very coarse texture /10.5%/, very heavy texture /11%/, salinity-alkalinity /10%/, waterlogging /3.0%/ and shallow depth /8.5%/. In 26% of the soils hydrophysical properties are moderately unfavourable due to coarse texture /11%/, heavy texture /12%/, and salinity-alkalinity in the deeper horizons /3%/; and only 31% of the soils can be characterized by good hydrophysical properties. In Fig. 3 the distribution of soils with good and unfavourable hydrophysical properties are illustrated in the 19 administrative regions of Hungary, indicating the main factors of soil limitations as well.

On the basis of global assessments, water will be the main limiting factor of future agricultural development in many parts of the World. The life and the satisfaction of the ever-growing food- and fibre-demand of the sharply increasing population depend - to a great extent - on the rational use of limited water resources. The water requirements of extensive /territorial extension of agricultural land in arid and semiarid regions/ and intensive /satisfaction of the increasing ecological requirements of highly productive

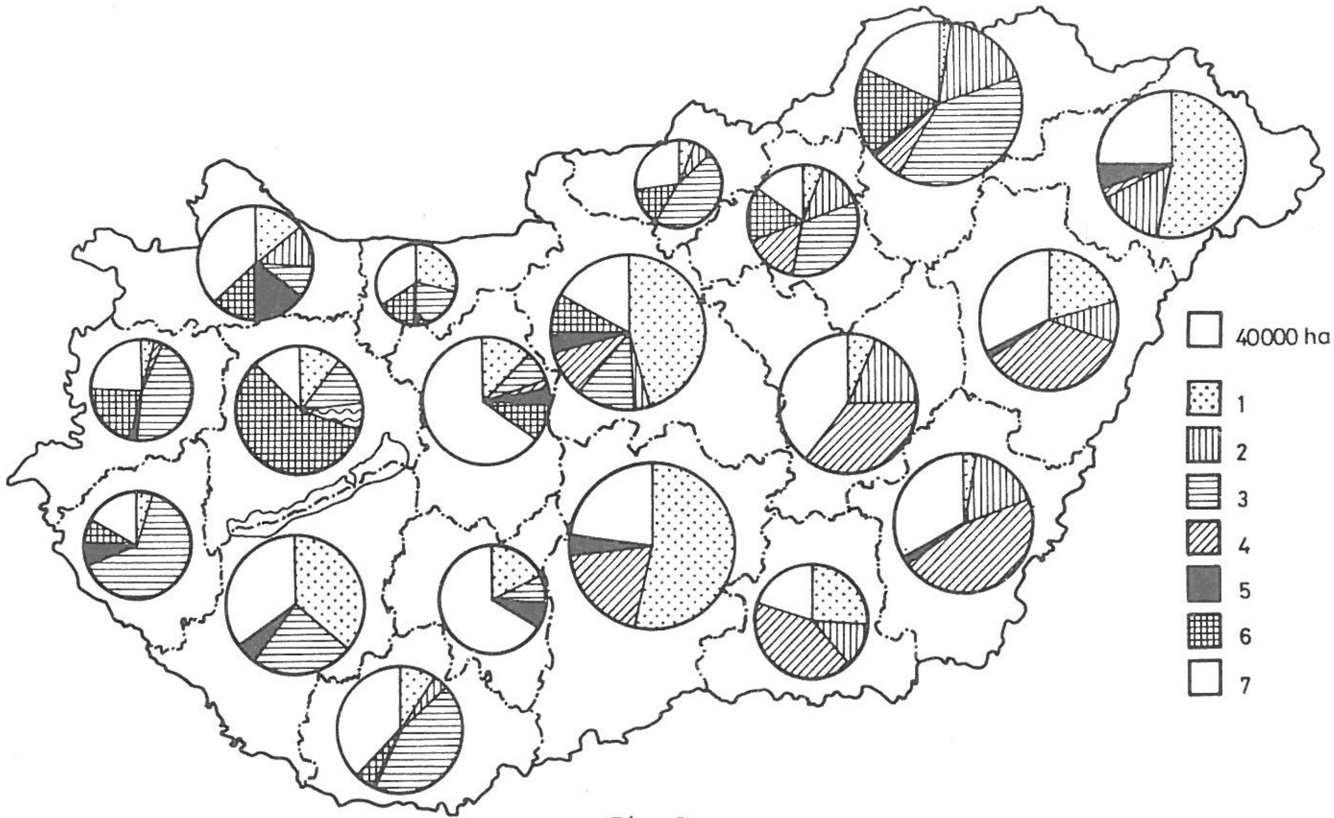


*Fig. 3*

Distribution of soils with good and unfavourable hydrophysical properties in the counties /administrative regions/ of Hungary. 1-6 = Soils with unfavourable hydrophysical properties: 1: due to coarse texture; 2: due to heavy texture; 3: due to clay accumulation in the B horizon; 4: due to salinity/alkalinity; 5: due to peat formation; 6: due to shallow depth; 7 = Soils with good hydrophysical properties varieties: optimation of their water- and nutrient supply; creation of favourable soil physical environment for mechanized agrotechnics/ are continuously increasing. At the same time good-quality water resources available for crop production are decreasing, because of the increasing water demand of other sectors of the national economy and social development, and the pollution of water resources. The exploitation of new water resources is often faced with water quality problems and the desalinization of seawater is far from being practical because of its high energy consumption and costs. Consequently, the increase of water use efficiency has particular significance all over the World.

*Soil water problems in Hungary*

The average annual precipitation is 620 mm in Hungary, but is shows a great territorial and time variability. As it is illustrated in Fig. 4, even the long-term annual average varies greatly: 450-500 mm in the driest territories, 500-550 mm in the central part, 550-600 mm in the other parts of the Great Hungarian Plain, in the Small Hungarian Plain and in the "Mezőföld" part of Transdanubia, 600-700 mm in the largest part of Transdanubia, increasing westwards up to 800-850 mm in the Western Pre-Alpian Region. The annual average temperature and, consequently the potential evapotranspiration shows similar, but opposite tendency: 11 °C → 9 °C within the 10.5-10.6 °C average for the country; 800 mm → 550 mm within the 650 mm country average.

The annual water balance is negative in the Hungarian Plain: 500-600 mm precipitation vs. 680-720 mm potential evapotranspiration /National Plan for Water Management, 1964; STEFANOVITS, 1968/. The negative water balance

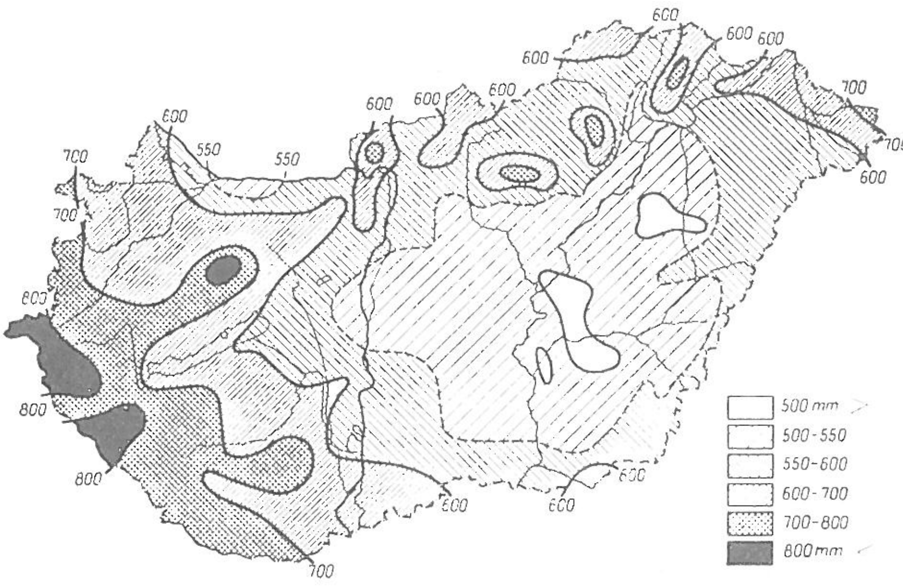


*Fig. 4*
The distribution of average annual precipitation in Hungary /1901-1950/

is equilibrated by horizontal flow /on the surface as runoff; in the unsaturated zone as horizontal flow of moisture, seepage; and in the saturated zone as groundwater flow/ which leads to the accumulation of soluble constituents, the weathering products of a large watershed /in this case the Carpathian Basin/ in the deeper parts of the area /in this case in the Hungarian Plain/. This "evaporative basin" character of the Hungarian Plain is the main reason for the predominance of accumulation processes /accumulation of water soluble salts, carbonates, etc./ in soil vs. leaching, and its consequence, the wide-spread occurrence of salt affected soils under such climatic conditions /SZABOLCS et al., 1969/.

The present 500-600 mm average annual precipitation may cover the water requirements of the main agricultural crops of Hungary even in the case of the present and the forecasted higher yield levels. The present yield level can be characterized by 5 t/ha wheat, 6 t/ha maize, 37 t/ha sugarbeet, 2 t/ha sunflower, 18 t/ha potatoes and 5 t/ha alphalpha hay /Statistical Pocket Book on Hungarian Agriculture, 1987/. However, this average shows extremely high spatial /even micro-territorial/ and time variabilities /monthly, weekly, daily fluctuations; intensive local rains/. Under such conditions a considerable part of atmospheric precipitation is lost by surface runoff, by downward filtration /through the soil profile into the groundwater → filtration losses/ and by physical evaporation. According to the long-term meteorological prognosis precipitation will not be more in the future /or may even be less as a result of the global warming-up of the near-surface atmosphere due to the "greenhouse effect"/ and will not be more evenly distributed in space and time.

The non-uniform rainfall distribution is one reason of the extreme moisture regime, the simultaneous hazard of waterlogging or overmoistening and drought sensitivity in large areas of Hungary, sometimes on the same places /micro-region, agricultural field, etc./ within a short period. The other reasons are:

- the relief /in addition to undulating surfaces the heterogeneous micro-relief of the "flat" Hungarian Plain/;
- the heterogeneous soil cover of Hungary, which is the result of the high spatial variability of all soil forming factors /climate, geology, geomorphology, hydrology, vegetation, time elapsing from the beginning of soil formation, influence of man/; [A good, but rather extreme example of this high spatial and time variability is the mosaic-like soil pattern of the Hortobágy salt affected area with the occurrence of waterlogged, overmoistened and dry spots near to each other, and their rapidly changing boundaries.]
- the unfavourable hydrophysical properties of some soils.

These properties, which are the limiting factors of the adequate water supply of plants, are schematically summarized in Fig. 5:

- In coarse-textured soils the limited water storage capacity is mainly due to the limited water retention, the extremely high infiltration rate and hydraulic conductivity.

- In the case of a surface crust or a compact soil layer near to the surface, not only the root penetration is impeded, but the infiltration is also limited, which create an extreme moisture regime:

- oversaturation /→ aeration problems → anaerobic biological processes → reduction → decreasing availability of plant nutrients/, temporary waterlogging and surface runoff /→ laterial erosion/ after rainfall or irrigation;
- drought sensitivity /← limited water storage capacity + high evaporation losses/ during dry periods, even under irrigated conditions.

- Crack formation in swelling clays causes another water problem. Some of the rain or irrigation water flows very rapidly through the open cracks of the dry soil, partly directly to the groundwater. These "filtration losses" diminish water storage in the soil, decrease water use efficiency and, at the same time, may result in a rise of the water table, which may be accompanied by such unfavourable processes as waterlogging, oversaturation /in the case of a high water table/ or secondary salinization and alkalization /in the case of a shallow, stagnant, saline groundwarer/. During dry periods, the soil may dry out deeply through the deep and wide cracks /→ considerable evaporation losses/. In rainy seasons the clogging cracks impede deep percolation and result infiltration problems, mentioned above.

- Low availability of soil moisture can be the consequence of one or more of the following factors:
- high matric potential /in the case of heavy-textured and/or highly $Na^+$-saturated soils/;
- high osmotic potential /in the case of high salinity/;
- low transport coefficients.

According to our investigations /VÁRALLYAY, 1987/ on a large number of representative soils from the Hungarian Plain the conclusion was drawn that in many cases the low transport coefficients /unsaturated conductivity, k; diffusivity, D/ are responsible for the non-adequate water supply of plants. The flux (V) of moisture from the wet soil to the plant roots - in spite of the high suction gradient - is extremely slow through the relatively dry, thin, "film-like" moisture depletion zone formed around plant roots. When this flux is lower than the rate of evapotranspiration ($V< ET$) the water supply of plants is limited and plants show water deficiency symptoms in spite of the relatively high average moisture content of the soil bulk /Fig. 5/.

Water uptake of plants is one reason of the peculiar micro-distribution pattern of soil moisture. The other reason is that the combination of various flow mechanisms can be characterized by very different fluxes /VÁRALLYAY, 1988a/:
- "by-pass flow" /through the open cracks into the deeper layers or into the groundwater - without considerable wetting of structural elements/;
- mostly downward flow from the soil surface through the peds;
- mostly lateral flow from the water-filled cracks into soil aggregates.

There are three main consequences of the high spatial and time variabilities of soil moisture regime:
- large yield variations within territories /within a region, a watershed, a farm or even within an agricultural field: natural heterogeneity of plant canopies/;
- high yield fluctuations depending on the dynamism of micro-scale soil moisture pattern, determining the water supply of crops;
- the necessity of a "double face" soil moisture control: ensuring /or at least making possible/ the drainage of the excess amount of water and giving the necessary amount of water, simultaneously /DARAB and FERENCZ, 1969; PETRASOVITS, 1982/.

The possibilities of both drainage and irrigation are limited in Hungary, because of the following facts:

(a) Drainage would be - temporarily - necessary in some hundred thousand hectares, however, it was implemented and is properly used in some ten thousand hectares. The main drainage limitations in Hungary are as follows:
   - poor vertical drainage of the soil profile, due to heavy texture, high amount of expanding clay minerals /+$Na-CO_3HCO_3$ type salinity, high alkalinity → high ESP, in salt affected soils/ → high rate of swelling → very low permeability and hydraulic conductivity;
   - lack of frost-free period during winter;

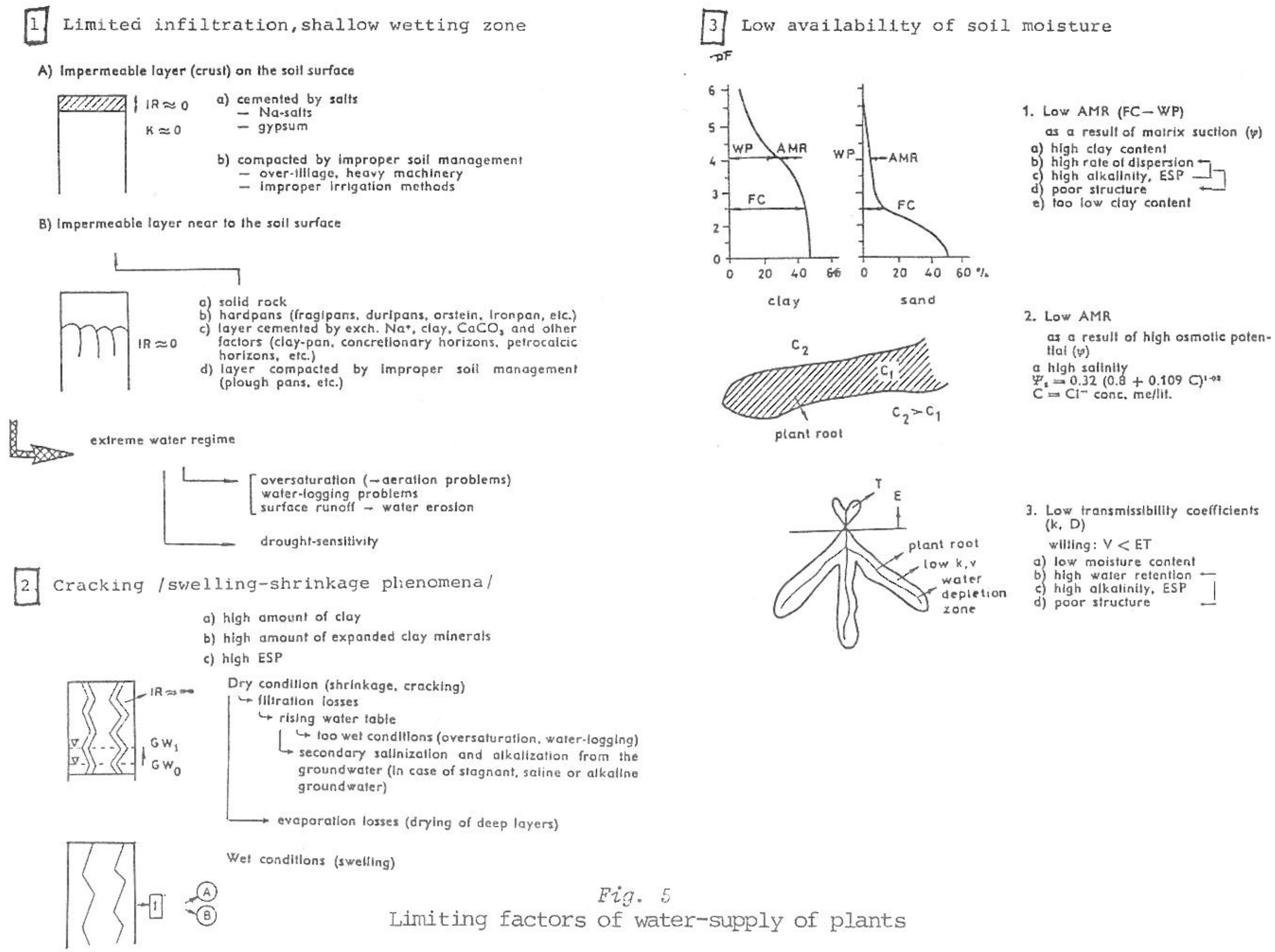


*Fig. 5*
Limiting factors of water-supply of plants

- lack of drainwater recipient /there is no sea or uncultivated land where the saline drainwaters can be placed without environmental deteriorations and we cannot put the drainwaters into rivers and canals because of water quality control regulations/.

(b) Irrigation. The potential irrigated area in Hungary is about 600 000-700 000 hectares, 7% of the total 93 032 $km^2$ area, and 10% of the 6.5 million hectares of agricultural land in the country. The present irrigation capacity is about 350 000 hectares, and in the last /rather dry/ years only 150 000 hectares were irrigated. This is mainly due to the facts that Hungary is situated in the zone of supplementary irrigation and the obtained yield surplus cover or exceed the high irrigation costs only in extremely dry years, or years with a dry vegetation season or critical periods. The irrigation potential is limited by the relief and the limited amount of good-quality irrigation water /SZALAI, 1989/. The quantity of irrigation water is limited by the following facts:

/i/ Most of the rivers /85-90% of their water quantity/ flow in from, and flow out to neighbouring countries: Hungary gets a certain amount of water with a certain quality at the entrance points of the rivers, and we have to guarantee a certain quantity and quality at the southern borders - even during the critical low water periods. Consequently, this most important source of irrigation water is limited, especially in the critical dry periods; and will not grow in the future in spite of the "high-water saving" fluctuation moderating activites, as reservoir construction, etc.

/ii/ A considerable part of the subsurface waters /especially in the Great Hungarian Plain/ cannot be used for irrigation because their poor quality does not fit the Hungarian irrigation water quality requirements. Another part of subsurface waters cannot be used because of environment control regulations preventing the lowering of the water table and its ecological consequences /e.g. in the Danube-Tisza Interfluve sand plateau/. The largest groundwater resource which can be used for irrigation is located in the Small Hungarian Plain, stored in the huge gravel strata of the Danube alluvial terrace.

/iii/ The increasing demand and water use of the other sectors of national economy /animal husbandry, industry, etc./ and social development /urbanization, rural development: drinking water supply and canalization; recreation; environment protection; etc./.

/iv/ The use of water for various purposes often results in unfavourable changes in water quality, which may limit their use for irrigation purposes.

The only way to solve this contradiction between the increasing demand of water in intensive agricultural development /higher yields, mechanized agrotechnics, etc./ and the limited and further decreasing water resources available for crop production is the increase of water use efficiency, in which soil water management has particular importance /PETRASOVITS, 1982; VÁRALLYAY, 1985a, 1987, 1988b, 1989a/.

*Soil water management tasks*

In the last years a comprehensive system of scientifically-based soil water management was elaborated and efficiently used in Hungary. The conceptual model of this system is shown in Fig. 6. On the Figure, the logical sequence of consecutive steps towards proper soil moisture control are summarized, with special attention to the registration of soil properties, from the selection of necessary parameters to the realization of various actions for the control and optimation of soil moisture regime.

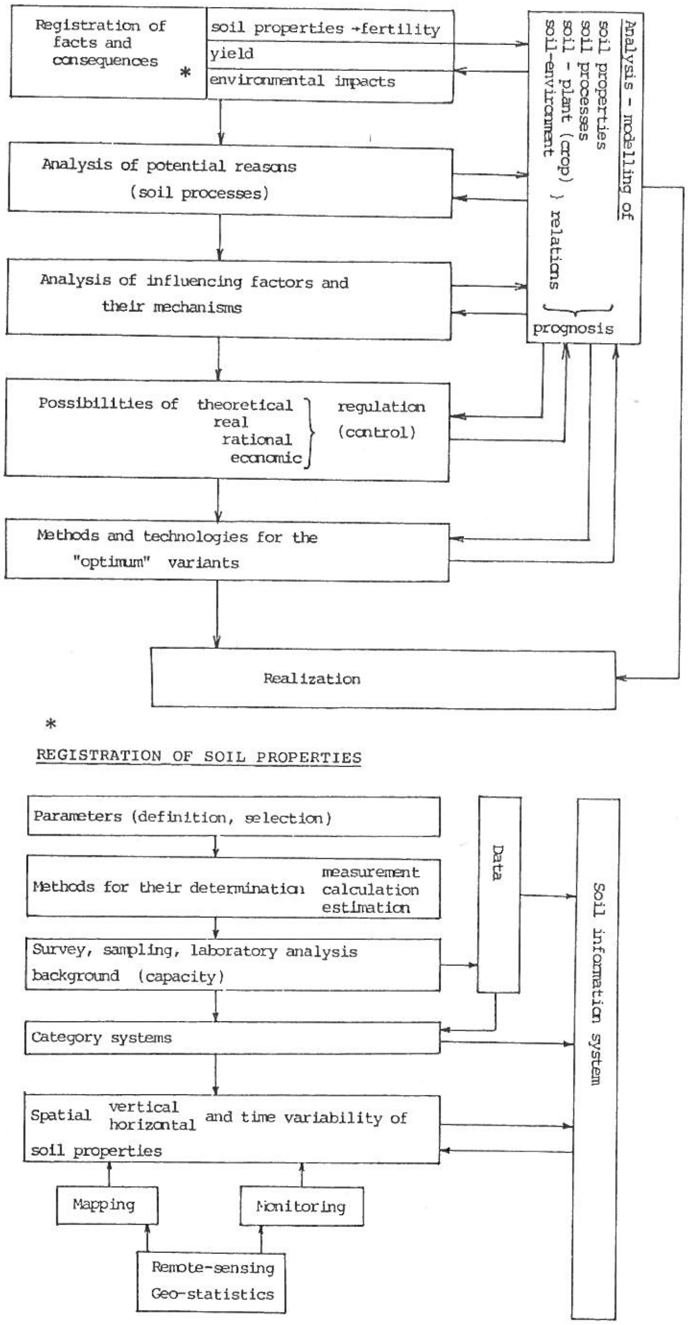


*Fig. 6*
Conceptual model of soil water management

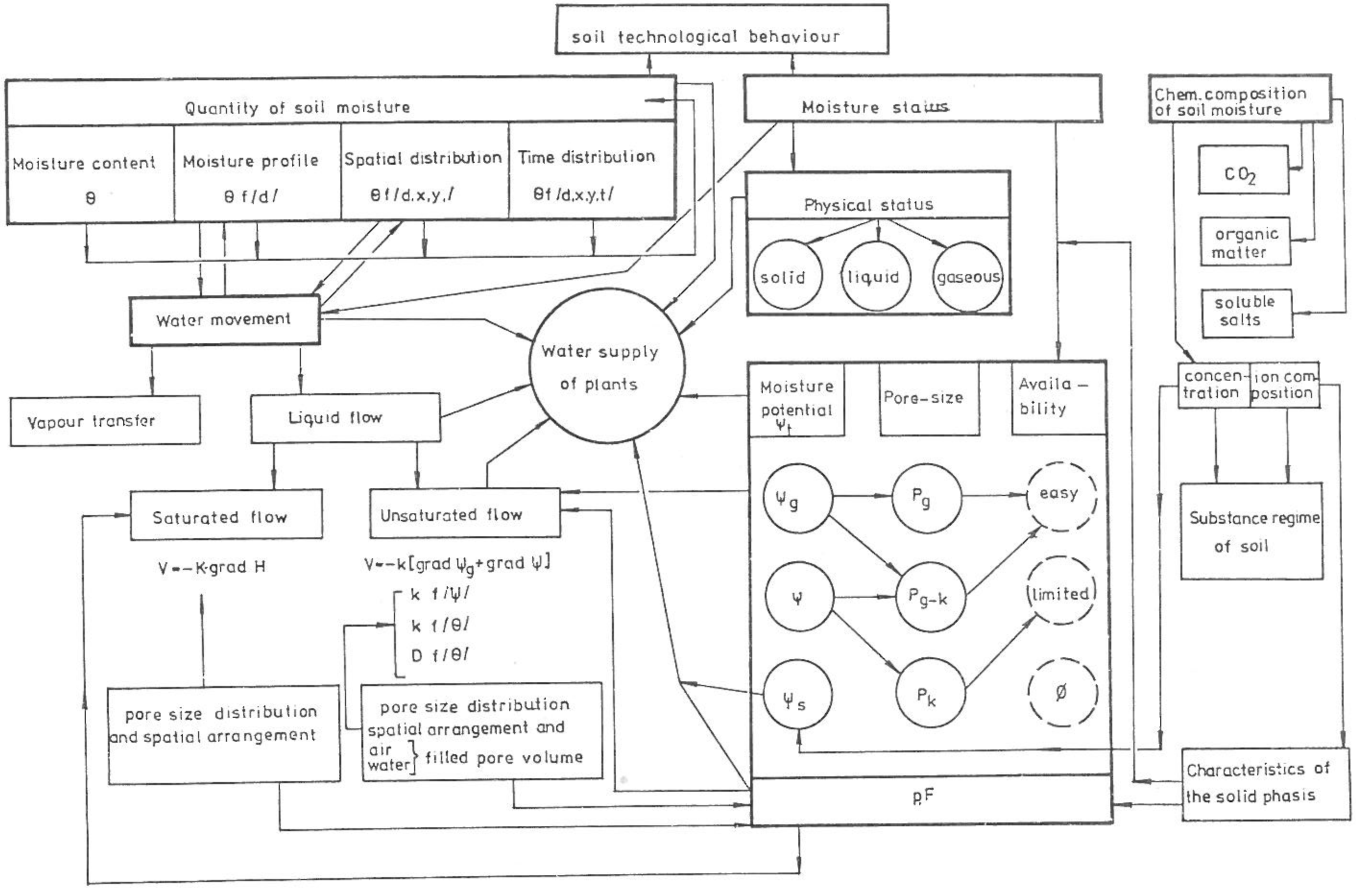


*Fig. 7*
Main characteristics of soil moisture regime

The main objectives of soil water management are:

(a) adequate water supply of plants /native vegetation and cultivated crops/;
(b) creation of favourable ecological micro-environment /aeration, nutrient supply ⇄ microbial activity/ for plants;
(c) maintenance or increase of soil fertility: favourably influencing soil processes, such as abiotic and biotic transport and transformation;
(d) establishment of optimum technological environment for various agrotechnical operations with low energy consumption in good quality and with minimum soil deteriorations.

The necessity and conditions of moisture regime regulations are determined by:

- climatic /weather/ conditions, especially temperature, precipitation and evaporation;
- other natural water supplies, as surface runoff, seepage and groundwater;
- relief;
- requirements of plants /cultivated crops/;
- physical and hydrophysical properties of soils
  - soil profile characteristics /sequence and thickness of soil horizon and layers/;
  - physical-hydrophysical properties of the various horizons /texture; structure; porosity, pore-geometry and pore architecture; moisture content, status and chemical composition; soil moisture constants, like total and field capacity, wilting percentage, available moisture range; infiltration rate; saturated and unsaturated hydraulic conductivity/;
  - other /mineralogical, physico-chemical, chemical and biological/ soil properties influencing the hydrophysical characteristics.

The main characteristics of soil moisture regime are summarized in Fig. 7.

For the exact characterization of soil moisture regime, quantitative information are required on these parameters, including their spatial /vertical and horizontal/ and time variabilities and existing relationships. These factors determine the field water cycle and the "fate" of water in the soil /as it is shown in Fig. 8/, which can be quantitatively characterized by factorial field water balances /VÁRALLYAY, 1985a/.

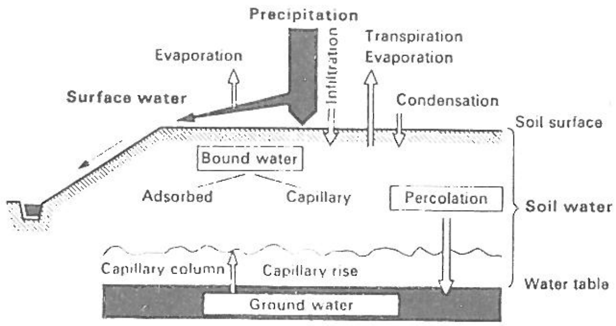


*Fig. 8*
The fate of water in soil

In Hungary /especially in the Hungarian Plain/ the basic aim of soil water management cannot be other, than:

(a) to help infiltration into the soil /prevention or moderation of surface runoff and physical evaporation/;

(b) to increase water storage within the soil /prevention of filtration and seepage losses/; and

(c) to increase the availability of water for plants /cultivated crops/.

The final aim of all direct /irrigation, groundwater control, drainage/ and indirect /landuse, cropping pattern and crop rotation, agrotechnics, soil reclamation/ measures towards the optimation of soil moisture regime is to ensure these requirements, and to stabilize and/or modify landsite characteristics and soil properties accordingly. As an example, the impacts of various types of soil amelioration on landsite and soil characteristics are summarized in Fig. 9.

For the establishment of an efficient soil moisture control adequate soil information /exact, accurate, quantitative, reproducible, easily measurable, territorial data on well-defined soil characteristics/ are required on various levels /national, regional, farm, field/ and in all phases of the action /judgement of necessity of soil moisture regulation; selection of its necessary elements; planning; implementation; control, maintenance and efficient use; forecast of possible impacts; monitoring changes and registration of consequences/.

Hungarian soil science and soil survey-analysis practice can satisfy these sharply increasing needs more and more efficiently. Some of the main results are summarized below, according to the steps of the conceptual model shown in Fig. 6.

*Scientific results, information bases and their practical applications for soil water management in Hungary*

(1)

A comprehensive soil survey-soil analysis system was developed for the determination of physical and hydrophysical characteristics of soils /VÁRALLYAY, 1987, 1988b, 1989a/:

(a) The exact parameters of these characteristics, which are required for the planning of various soil moisture control measures, as well as for the forecast and registration of their impacts, were selected and precisely defined. The most important characteristics of soil moisture regime are summarized in Fig. 7.

(b) Methods and techniques were elaborated or adapted for the measurement, calculation or estimation of these characteristics . E.g.:
   - for the in situ determination of soil moisture content and its vertical and horizontal distribution /in the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences - RISSAC -, Budapest; and in the Research Center for Water Resources - VITUKI - Budapest/;
   - for the determination /VÁRALLYAY, 1973a/, calculation /on the basis of direct measurement of simple soil parameters as particle size distribution, bulk density and organic matter content/ /RAJKAI, 1987--1988/ and mathematical description /VÁRALLYAY et al., 1979/ of moisture retention /pF/ curves and soil moisture constants, as total water storage capacity /~porosity/ - WC; field capacity - FC; wilting percentage - WP; and available moisture range - AMR;
   - for the determination of saturated hydraulic conductivity - $K_{sat}$ - on undisturbed soil cores and soil columns /VÁRALLYAY, 1973b/;

| | Soil /land-site/ characteristics \ Type of amelioration | Land levelling | Improvement of acid soils | Reclamation of salt affected soils | Reclamation of sandy soils | Deep loosening | Soil conditioning | Drainage | Irrigation | Groundwater control | Surface drainage | Amelioration of peats | Water erosion control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | Microrelief | + | | | | | | | | | O | | + |
| 2 | Soil variant | + | O | + | + | | | | | | | + | + |
| 3 | Layering | + | | O | O | | | | | | | + | + |
| 4 | Depth of soil | O | | + | O | + | | | | | | + | + |
| 5 | Soil reaction /pH. $y_1$, $v_2$; alkalinity/ | | + | + | | | | | | | | | |
| 6 | $CaCO_3$- content | | + | O | O | | | | | | | | |
| 7 | Water soluble salt content /%;profile; composition/ | | | + | | | | | O | | O | | |
| 8 | Exchangeable $Na^+$ content /ESP/ | | | + | | | | | O | | O | | |
| 9 | Organic matter content | | | | + | | | | | | | + | O |
| 10 | Depth of humus horizon | + | | | + | | | | | | | + | + |
| 11 | Cation exchange capacity /CEC/ | | | | + | | | | | | | | O |
| 12 | Development and stability of soil structure | | O | O | O | O | + | | O | | | | |
| 13 | Compactness | | O | O | O | + | + | | O | | O | | O |
| 14 | Total water capacity, $WC_T$ | | | O | + | + | + | | | | | + | |
| 15 | Field capacity, FC | | | O | + | + | + | | | | | + | |
| 16 | Wilting percentage, WP | | | + | | | | | | | | + | |
| 17 | Available moisture range /AMR/ | O | | + | + | + | + | O | + | + | + | | + |
| 18 | Infiltration rate | | | + | O | + | + | O | | | O | | + |
| 19 | Hydraulic conductivity | | | + | + | + | + | | | | | | |
| 20 | Capillary conductivity | | | O | O | | + | | | + | | | |
| 21 | Rate of surface runoff | O | | | | + | + | + | O | O | + | | + |
| 22 | Waterlogging hazard | O | | O | | O | O | + | O | + | + | + | O |
| 23 | Depth and horizontal flow of groundwater | | | O | | | | + | O | + | O | + | |
| 24 | Salt concentration and ion composition of groundwater | | | + | | | | O | O | + | O | O | |

\+ primary impact    O potential side-effect

*Fig. 9*

Impact of soil amelioration on various soil /landsite/ characteristics

- for the determination /VÁRALLYAY, 1974a, 1974b/ and calculation /on the basis of directly measured saturated hydraulic conductivity and measured or calculated water retention curves: RAJKAI, 1984; VÁRALLYAY, 1987/ of unsaturated hydraulic conductivity, $k_{unsat}$: k-Ψ, k-Θ relationships.

(c) Special attention was paid to the exact description of solute transport processes /convection, hydrodynamic dispersion, diffusion; capillary transport from the groundwater to the overlying soil horizons; etc./ and flow anomalies in salt affected soils /"salt sieving" phenomena; non-Darcian flow behaviour; increase of $K_{sat}$ with an increase of acting hydraulic gradient → increasing rate of the "mobile" fraction of soil solution; etc./ /KOVDA and SZABOLCS, 1979; VÁRALLYAY, 1988a; VÁRALLYAY and MIRONENKO, 1979/.

(d) A five-step computerized model was established for the exact description and quantitative characterization of water and solute transport processes in the unsaturated zones of stratified /layered/ soil profiles above fluctuating groundwater table; for the estimation of the quantity of water and soluble constituents that may enter the soil profile from the groundwater by upward capillary transport; and - on this basis - for the calculation of the "optimum depth" /ensuring additional moisture supply for plants from good-quality groundwater/ and "critical depth" /preventing salt accumulation from saline, poor-quality groundwater/ of the groundwater table /VÁRALLYAY, 1974b, 1987; VÁRALLYAY and MIRONENKO, 1979/.

(2)

The soil survey sampling, soil and water analysis capacity for the determination of the necessary soil /and water/ parameters had been set up during the last years, with the establishment of five well-equipped regional soil physical-hydrophysical laboratories within the system of the Hungarian National Crop and Soil Conservation Service of the Ministry of Agriculture and Food /VÁRALLYAY, 1987/.

(3)

For the national and regional planning of soil water management a category system was elaborated for the classification of soils according to their hydrophysical properties /texture, water storage capacity, field capacity, wilting percentage, available moisture range, infiltration rate, saturated and unsaturated hydraulic conductivities; layer-sequence of the soil profile/, and the map of these categories was prepared in the scale of 1:100 000 /VÁRALLYAY, 1989c, VÁRALLYAY et al., 1980, 1985/.

Another system was elaborated for the large-scale /1:10 000-1:25 000/ mapping of hydrophysical properties of soils and characteristics of the soil moisture regime. These maps represent a comprehensive computer-stored territorial soil data base for farm- and field- /plot/ level operations of soil water management /VÁRALLYAY, 1987, 1989c/.

All of these information /including contours!/ were computer-stored in the Hungarian Soil Information System /HunSIS = TIR/ /CSILLAG et al., 1988/.

(4)

On the basis of a semi-quantitative analysis of the field water balance /Fig. 8/ and soil moisture regime, their determining and influencing factors, as well as their consequences on the mass and energy regimes of soil formation and soil degradation processes, Hungarian soils were classified into eleven main moisture regime and thirteen main substance regime types. The maps of these categories were prepared in the scale of 1:500 000 /VÁRALLYAY, 1985a, 1987, 1989c/. The main problems and possibilities of soil moisture control were summarized for each type and general recommendations were given for its practical realization.

On the basis of these maps and maps on relief and groundwater conditions two additional maps were prepared in 1:100 000 scale:
- on the possibilities and soil conditions of irrigation without any harmful environmental side-effects /salinization-alkalization, waterlogging, peat formation /SZABOLCS et al., 1969/;
- on the probability of waterlogging hazard due to soil conditions and potential possibilities of its prevention or moderation /VÁRALLYAY, 1989c/.

(5)

The establishment of a rational and efficient soil moisture control necessitates adequate information on the potential impacts of the planned control measures before their realization. For such prognoses verified models on the existing processes and their mechanisms /including the expression of the partial and integral effects of influencing factors and their relationships/ can be efficiently used. In the last years successful researches were carried out in our Institute /RISSAC/ on the modelling of field water cycle and soil moisture regime.

On the basis of high probability prognoses /"impact forecasts"/ the most promising variants can be selected from the potential possibilities /alternatives/ according to the given conditions /natural and socio-economical conditions; plans for production; environmental consequences, etc./, and proper methods and technologies can be elaborated and implemented for these optimum variants.

During the last years two prognosis systems have been properly used in Hungarian water management practice:
- prognosis on the integral impacts of the Kisköre Irrigation System /on the Tisza river in the Hungarian Plain/, on the salinity-alkalinity status of soils, the hazard of salinization-alkalization processes /SZABOLCS et al., 1969/;
- prognosis on the potential impacts of the Gabcikovo-Nagymaros hydro-power station /on the Danube river between Czechoslovakia and Hungary/ on the moisture regime and soil processes in the area concerned.

On the basis of these studies conclusions were drawn on the possibilities of prevention of unfavourable environmental side-effects and for their practical realization.

The establishment of a monitoring-system for the continuous registration of natural and human-induced changes in soil properties and soil moisture regime is an important part of the control system. The data base of spatial monitoring gives possibilities for the verification of prognosis models, improvement of their accuracy and probability, as well as for the establishment of new models. With their application the probability of forecasted impacts can be efficiently improved, and - on these bases - the effectivity and efficiency of soil water management can be significantly increased.

( 6 )

Almost all of the potential elements of soil water management are - simultaneously - effective measures for environment protection /VÁRALLYAY, 1986/, as it can be seen in Table 1.

The presented results and information were widely and efficiently used in Hungarian soil water management practice, e.g. for the elaboration of adequate tillage practices; in drainage design /necessity, type, spacing, slope, capacity, filtering, etc./; in irrigation planning /necessity, scheduling, quantity and quality requirements, frequency, intensity, method, po-

*Table 1*

Possibilities and methods of soil water management and their environmental impacts

| Possibilities | | Methods | Environmental impacts |
|---|---|---|---|
| Surface runoff | Prevention of moderation of | System of land use and agrotechnics for soil conservation: increase of the time for infiltration /moderation of slope; establishment of permanent and dense vegetation; tillage practice/; improvement of infiltration /tillage, including deep-loosening/ | 1, 1a, 5a, 8 |
| Surface evaporation | | Improvement of infiltration /tillage practice, including deep-loosening/; prevention of surface accumulation of waters | 2, 4 |
| Filtration losses /feeding of groundwater/ | | Increase of water storage capacity of soil; moderation of soil cracking /swelling-shrinkage/; surface and subsurface water regulation | 5b, 7 |
| Rise of groundwater table | | Prevention or moderation of filtration losses; groundwater regulation /pumping, drainage/ | 2, 3, 6b, 5c |
| Infiltration to the soil | help of | Prevention or moderation of surface runoff /see above/ | 1, 4, 6a, 7 |
| Storage of water within the soil | | Increase of water storage capacity of soil /help infiltration and improve water retention/: adequate land-use and cropping pattern; soil reclamation; soil conditioning | 4, 5b, 7 |
| Irrigation | | Various irrigation practices | 4, 7; 9, 10 |
| Surface / Subsurface } drainage | | Surface and subsurface } drainage practices | 1, 2, 3, 5c, 6, 7; 11 |

Environmental impacts:

| Favourable influences | | Non-favourable side-effects |
|---|---|---|
| Prevention or moderation of the following unfavourable side-effects | | |
| 1. Soil erosion by water; solifluction<br>1a. Sedimentation<br>2. Secondary salinization/alkalization<br>3. Waterlogging; peat bog formation<br>4. Drought-sensitivity; cracking of soils | 5a. Surface runoff, 5b. Leaching, 5c. Immobilization } of plant nutrients /→ surface waters eutrophication/ /→ subsurface waters/<br>6. Formation of phyto-toxic compounds<br>7. "Biological degradation"<br>8. Flood hazard in the catchment area | 9. Overmoistening; waterlogging; peat-bog formation; salinization-alkalization<br>10. Leaching of plant nutrients<br>11. Drought sensitivity |

tential side-effects and their prevention/ /SZALAI, 1989/; in groundwater control /regulation of seasonal fluctuation, quality control, prevention of pollution, etc./; in erosion control /prevention or moderation of surface runoff, etc./. Because of the close relationship between the moisture and nutrient regime of soils /VÁRALLYAY, 1985b/ soil water management and its information base represent a considerable help in the establishment of a rational fertilization system, guaranteeing the nutrient-supply of plants without any harmful side-effect on soil /acidification, structure deteriorations, biological degradation/ or on water resources /P "contamination" of surface waters → eutrophication → silting up; nitrate contamination of subsurface waters; etc./ /SARKADI and VÁRALLYAY, 1989/.

In the future the importance of proper soil water management will be sharply increasing both from the viewpoints of agricultural production and environment control. Consequently, all efforts have to be taken to increase water use efficiency and to optimize soil moisture regime in harmony with soil fertility control, soil conservation and environment protection.

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