SOIL RELATED REASONS AND CONSEQUENCES OF EXTREME HYDROLOGICAL SITUATIONS (FLOODS, WATERLOGGING – DROUGHTS)

György VÁRALLYAY[1]

Review article UDK 631.432.2(439 Carpathian Basin)

ABSTRACT

The most important elements of sustainable development in the Carpathian Basin are the rational use and conservation of soil and water resources, maintaining their favourable "quality" and desirable multi-functionality. These are the main factors of multipurpose biomass production and environment protection: may help to prevent, eliminate or reduce extreme moisture situations (floods, waterlogging vs. droughts), unfavourable soil degradation processes limiting soil fertility/productivity, and their harmful economical/ecological/environmental/social consequences [9, 11, 14, 16].

Keywords: *soil moisture regime, water storage, waterlogging hazard, drought sensitivity, soil moisture control*

INTRODUCTION

The **natural conditions** (climate, water, soil and biological resources) **of the Carpathian Basin** (particularly lowlands and plains) are *generally favourable* for rain fed biomass production. These conditions, however, show extremely *high,* irregular, consequently hardly predictable spatial and temporal *variability;* often *extremes;* and sensitively react to various natural or human-induced stresses. The main constraints are: extreme moisture regime; soil degradation processes; and unfavourable changes in the biogeochemical cycles of elements, especially of plant nutrients and environmental pollutants [2, 7, 10].

The Carpathian Basin is a greatly **"water-dependent" region***,* where the soil–water relationships considerably influence, sometimes determine the type and rate of weathering, soil formation and soil degradation processes; the moisture and substance regimes; the abiotic and biotic transport and transformation; mass and energy regimes in the „geological formation–soil–water–biota–plants–near surface atmosphere"

[1] Hungarian Academy of Sciences, Centre for Agricultural Research, Institute for Soil Sciences and Agricultural Chemistry, H-1022 Budapest, Herman Ottó út 15, g.varallyay@rissac.hu

continuum; soil fertility/productivity; the yields and yield fluctuation of crops; and environmental conditions [17,18].

According to the meteorological/hydrological/ ecological forecasts the risk, probability, frequency, duration and intensity of **extreme meteorological and hydrological events** will be increasing in the future and their unfavourable economical, ecological and social consequences will be more and more serious, sometimes catastrophic [4, 5, 12]. Consequently, water will be the determining (hopefully not limiting) factor of food security and environmental safety and the **improvement of water use efficiency** (including soil moisture control) will be the key issue of multipurpose biomass production, environment protection and sustainable social development.

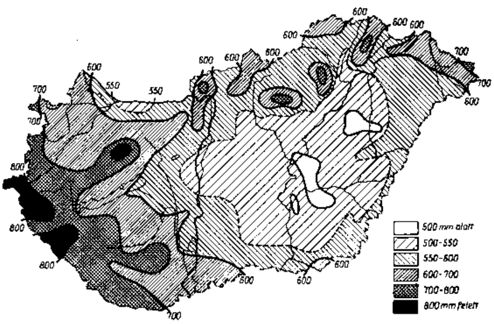
LIMITED WATER RESOURCES AND THEIR HIGH VARIABILITY

The Carpathian Basin is *generally rich* in water resources, especially in the low-lying parts of the Pannonian Plains, as the bottom of this large water catchment area. On the contrary, during certain "critical periods" in some "critical areas" the water resources are *limited* and **"extreme" hydrological situations**:

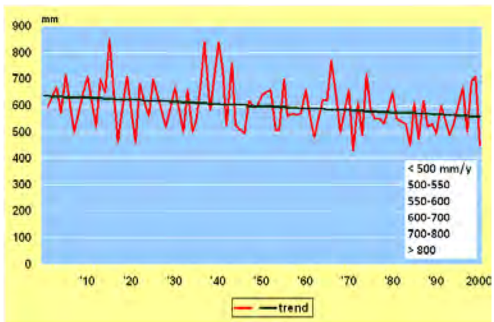
- *surplus* amount of water: flood, water-logging, "over-moistening" hazard;
- *shortage* of water: drought sensitivity is characteristic [4, 12, 14].

The average 450–600 mm annual **atmospheric precipitation** in the Pannonian Plains may cover the water requirement of the main crops even at high yield levels, and it gives reality for efficient "rain fed" biomass production. But the average shows *extremely high territorial* (Fig. 1A) *and temporal* (Fig. 1B, 1C and 1D) *variability*–even at micro-scale.

A



B



C D

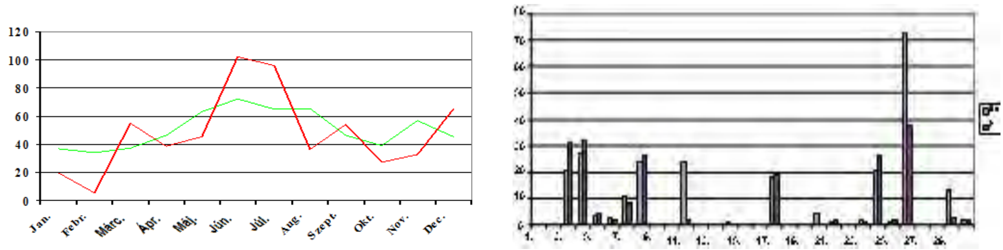


Figure 1. Territorial and time distribution of atmospheric precipitation in Hungary. A. Territorial distribution of the 100-year average annual precipitation. B. Average annual precipitation in Hungary in the 20th century. C. Monthly distribution of the long-term average and 2008 annual precipitation. D. Daily distribution of monthly precipitation (May 2008) at two nearby meteorological stations.

A certain part of the atmospheric precipitation falls as highly intensive rain or hail. Their frequency, duration and intensity have considerably increased during the last years, resulting in serious environmental consequences: intense surface runoff and erosion (soil losses and sedimentation hazards) or even landslides; infrastructure damages, etc. In such cases only a limited (reduced) part of the rainwater is stored in the soil and is available for the biota, natural vegetation and cultivated crops, and giving additional water (irrigation) or draining the surplus amount of water (drainage) would be necessary. Both are faced with serious limitations in the Carpathian Basin: limited quantity of good quality water for irrigation; relief; poor horizontal and vertical drainage conditions. Therefore, all efforts have to be taken to collect, store and rationally use *rainwater* and to reduce its evaporation, surface runoff and deep filtration losses [3, 7, 12, 13].

The average quantity of incoming **surface waters** (rivers) is about 110-115 km^3/year in Hungary and it will not increase in the future, particularly not in the critical low-water periods, and a certain quantity and quality of transboundary surface waters must be guaranteed for the lower Danube Basin countries (at present this outflow is about 115-120 km^3 [4, 5].

The “available” quantity of **subsurface waters** is also limited.

The average depth and fluctuation of the groundwater table shows great territorial variability. The possibility of capillary transport from the groundwater to the overlying soil horizons, and to the active root zone can be significant only in the lowlands [20]. This capillary transport – in the case of good-quality groundwater – may considerably contribute to the water supply of plants, decreasing drought sensitivity, as in the Small Hungarian Plain (NW Hungary). But a considerable part of subsurface waters (especially in the poorly drained East Hungarian Plain) is of poor quality (high salinity, alkalinity, sodicity) and in such cases this capillary solute transport threatens with harmful salinization/sodification processes.

Another part of the subsurface waters cannot be used or (over)exploited because of the sink of the water table and its unfavourable ecological consequences, like the serious "desertification symptoms" in the Danube–Tisza Interfluve sand plateau [9, 12].

In addition to the hardly predictable water resources, there are two more reasons of **extreme soil moisture regime**:

- the heterogeneous *micro relief* of the „flat" lowland;
- the highly variable, sometimes mosaic-like *soil cover* and the unfavourable physical and hydro physical properties of some soils (mainly due to heavy texture, high clay and swelling clay content, or high sodium saturation: ESP) [8].

SOIL RESOURCES, SOIL AS THE LARGEST POTENTIAL NATURAL WATER STORAGE CAPACITY

As a result of the combined influence of the highly variable soil forming factors and soil processes a highly – even on micro-scale! – heterogeneous, **mosaic-like soil cover** developed in the Carpathian Basin.

Under the given environmental conditions, it is an important fact that **soil is the largest potential natural water reservoir** (water storage capacity). The 0-100 cm soil layer potentially may store more than half of the average annual precipitation (500-600 mm). About 50% of it is „available moisture content", which may satisfy the water requirement of the natural vegetation and cultivated crops – even at high biomass production and yield levels [2, 12, 16].

This favourable fact is quite contrary with the high and increasing risk, hazard, frequency and duration of **extreme hydrological events** (floods, waterlogging, over-moistening vs. drought) sometimes in the same place in the same year, which are characteristic features of the Pannonian Plains [4, 5, 9, 11]. Their *main reasons* are the high territorial and temporal variability of atmospheric precipitation; rain: snow ratio and snowmelt characteristics; relief (including micro relief); soil conditions; vegetation; land use practices. And their *main consequences* are water losses (evaporation, surface runoff, seepage, deep filtration); soil (organic matter and nutrients), biota, vegetation and yield losses; energy losses [7].

What are the main reasons of this "huge water storage capacity" – "extreme moisture situation" contradiction*?*

1. Only (?) 31% of Hungarian soils represent an "ideal case" for the efficient use of the potential water storage capacity, having "favourable" hydro physical properties, but 43% of the soils have unfavourable and 26% moderately favourable water management characteristics, because of various limiting factors, as it can be seen in Figure 2 [16, 21].

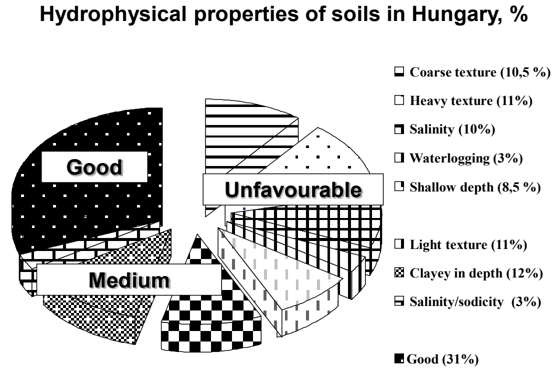


Figure 2. Water management characteristics of soils in Hungary and their reason

In the last years a comprehensive soil survey–analysis–categorization–mapping–monitoring system was developed for the exact characterization of *hydro physical properties*, modelling and forecast of the *water and solute regimes* of soils. The digital soil physical/ hydro physical database includes a 1:100 000 scale map of the hydro physical characteristics of soils. The map is shown in Figure 3 [13, 14, 21].

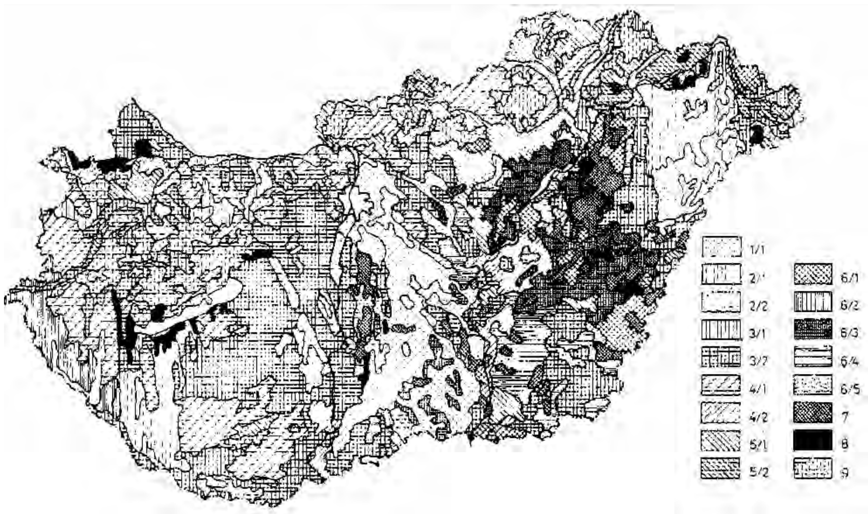


Figure 3. Hydro physical characteristics of soils in Hungary

1. Soils with very high IR, P and HC; low FC; very poor WR: **10.5%**.
2. Soils with high IR, P and HC; medium PC; and poor WR: **11.1%.**
3. Soils with good IR, P and HC; good FC; and good WR: **24.8%**.
4. Soils with moderate IR, P and HC; high FC; and good WR: **19.1%**.
5. Soils with moderate IR, poor P and HC; high PC and high WR: **6.2%**.
6. Soils with unfavourable water management: very low IR and K: **14.9%.**

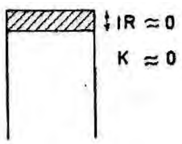
7. Soils with extremely unfavourable water management due to high salinity/sodicity: extremely low AMR, IR and K:**3.6%.**
8. Soils with good IR, P and HC; and very high FC (organic soils: **1.3%.**
9. Soils with extreme moisture regime due to shallow depth: **8.4%.** The main profile variants: (1) texture becomes lighter with depth (soils formed on relatively light-textured parent material): 2/1, 3/1. (2) uniform texture within the profile: 1/1, 2/2, 3/2, 4/2, 5/2. (3) relative clay accumulation in the horizon B: 4/1, 5/1. Profile variants of category 6: 6/1: highly compacted, heavy-textured soils with poor structure; 6/2: pseudogleys; 6/3. deep meadow solonetzes and solonetzic meadow soils; 6/4: soils with salinity/sodicity in the deeper horizons; 6/5: peaty meadow soils

2. The potential water storage capacity is not (or only partly) utilized because of the following reasons [9, 12, 16, 18]:
   - The pore space is not "empty": it is filled up by a previous source of water (rain, melted snow, capillary transport from groundwater, irrigation etc.): "*filled bottle effect";*
   - The infiltration of water (rain, melted snow) into the soil is prevented by the frozen topsoil: "*frozen bottle effect";*
   - The infiltration is prevented or reduced by a nearly impermeable soil layer on, or near to the soil surface: "*closed bottle effect"* (Fig. 4 (1));
   - The water retention of soil is poor and the infiltrated water is not stored in the soil, it only percolates through the soil profile: "*leaking bottle effect"* (Fig. 4 (2)).

The main reasons and consequences of these limiting factors are summarized in Figure 4.

1. Limited infiltration

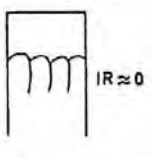
A. Impermeable layer (crust) on the soil surface



a) cemented by salts
   - Na salts
   - gypsum

b) compacted by improper soil management
   - over-tillage, heavy machinery
   - improper irrigation methods

B. Shallow wetting zones (low water storage capacity)

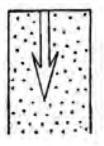


a) solid rock
b) hardpans (fragipans, duripans, orstein, ironpan etc.)
c) layer cemented by exch. Na^+, clay, $CaCO_3$ and other factors (clay-pan, concretionary horizons, petrocalcic horizons, etc.)
d) layer compacted by improper soil manage-ment (plough pans, etc.)

↓

extreme water regime
→ oversaturation (aeration problems)
waterlogging problems
surface runoff – water erosion
→ drought sensitivity

2. Limited water retention



IR, HC > FC → drought sensitivity

Figure 4. Limitations of utilizing the potential water storage capacity of soil

The soil moisture regime strongly influences, sometimes determines other soil ecological properties, such as air, heat and nutrient regimes, biological activity; soil fertility; the environmental sensitivity and tolerance limits of soil against various natural and human-induced stresses, including climate change, point source or quasi point source and diffuse soil pollution; and the soil technological indices for soil tillage and other agrotechnical operations [6, 13, 15, 19].

Sustainable soil management and moisture control

Rational land use and sustainable soil management are greatly water dependent in the Carpathian Basin [2, 3, 13, 14, 17].

As the direct moisture control actions, irrigation and drainage are faced with serious limitations (limited quantity of good quality irrigation water, relief; poor horizontal and vertical drainage conditions) all efforts have to be taken for the improvement of "rainwater efficiency" by a "two-way" ("double face") moisture control, which basic concept is the preference of "storage" instead of "drainage" (transport away)! The most important elements of such rational and sustainable soil moisture control are:

– help the infiltration of water into the soil;
– help the useful storage of infiltrated water within the soil without any unfavourable environmental consequences;
– reduce the immobile (strongly bound, "dead") fraction of the stored water;
– reduce evaporation, surface runoff and deep filtration losses of atmospheric precipitation and irrigation water;
– drain only the harmful surplus amount of water from the soil profile and from the area, improving vertical and horizontal drainage conditions (prevention of over-saturation and/or water-logging).

There are many possibilities for the practical realization of these basic objectives. Some of them are summarized in Table 1, indicating their potential environmental impacts [1, 12, 13, 17].

Scientific and technical development offer more and more new tools, techniques and technologies for such activities on the basis of our comprehensive digital soil physical/hydro physical database, which can be quantitatively interpreted for soil layers, soil profiles; physic-geographical, administrative, farming or mapping units (e.g. ecological region, water catchment area, county, settlement, farm, agricultural field etc.). Our task is to select and implement **proper and efficient site-specific technologies**. As it is clear from Table 1 most of these „moisture management actions" are – at the same time – efficient environment control measures and reduce the risk and unfavourable consequences of various natural and human-induced stresses (as soil degradation processes, nutrient stress, pollution hazard, etc.) [10, 14, 19].

Table 1. Elements and methods of soil moisture control with their environmental impacts

	Elements	**Methods**	**Environ-mental impacts***
Reducing	surface runoff	Increase in the duration of infiltration (moderation of slopes; terracing contour ploughing; establishment of permanent and dense vegetation cover; tillage; improvement of infiltration; soil conservation farming system)	1,1a 5a, 8
Reducing	Evaporation	Helping infiltration (tillage, deep loosening) Prevention of runoff and seepage, water accumulation	2,4
Reducing	feeding of ground-water by filtration losses	Increase in the water storage capacity of soil; moderation of cracking (soil reclamation); surface and subsurface water regulation	5b, 7
Reducing	rise of the water table	Minimization of filtration losses (↑); groundwater regulation (horizontal drainage)	2,3 5b,5c
Increasing	Infiltration	Minimization of surface runoff (tillage practices, deep loosening) (↑)	1,4,5a, 7
Increasing	water storage in soil in available form	Increase in the water retention of soil; adequate cropping pattern (crop selection)	4,5b,7
Irrigation		Irrigation; groundwater table regulation	4,5c,7, 9,10
Surface } drainage Subsurface		Surface } moisture control (drainage) Subsurface	1,2,3,5c, 6,7, 11

* Referring numbers: See below

Favourable environmental effects	Unfavourable environmental effects
Prevention, elimination, limitation or moderation of: – water erosion (1) – sedimentation (1a) – secondary salinization, alkalization (2) – peat formation, waterlogging, over-moistening (3) – drought sensitivity, cracking (4) – plant nutrient losses by: – surface runoff (→ surface waters eutrophication) (5a) – leaching (→ subsurface waters) (5b) – immobilization (5c) – formation of phytotoxic compounds (6) – "biological degradation" (7) – flood hazard (8)	– over moistening, waterlogging, peat and swamp formation, secondary salinization/ alkalization (9) – leaching of plant nutrients (10) – drought sensitivity (11)

CONCLUDING REMARKS

Soil management and soil moisture control have distinguished significance in rational land use and sustainable soil and water management in the Carpathian Basin. The present and expected increasing risk, frequency, duration and intensity of extreme (and irregular, consequently hardly predictable) climatic and hydrological events and moisture situations may result in serious (or even catastrophic) environmental damages and their unfavourable economical, ecological and social consequences [19]. **Proper and efficient soil and water management** may help to prevent, eliminate or reduce these extreme hydrological situations (floods, waterlogging vs. droughts), unfavourable soil degradation processes, and their harmful consequences. The proper control measures may satisfy the preconditions of soil resilience, the "quality maintenance" of this multifunctional, conditionally renewable natural resource, which are important elements of sustainable development, multipurpose biomass production and environment protection [2, 10, 19].

Acknowledgement

Part of the research was carried out in the frame of OTKA Project No. K-105789.

REFERENCES

[1] M. Birkás, Environmentally-sound adaptable tillage. Budapest: Akadémiai Kiadó, 2008.

[2] I. Láng, L. Csete and Zs. Harnos, Agro-ecological Potential of Hungarian Agriculture (In Hungarian) Budapest: Mezőgazd. Kiadó, 1983.

[3] T. Németh, P. Stefanovits and Gy. Várallyay, Gy., Hungarian Soil Conservation Strategy (In Hungarian). Budapest: Ministry of Environment Protection and Water Management, 2005.

[4] I. Pálfai (Ed.), 2000. The role and significance of water in the Hungarian Plain (In Hungarian) Békéscsaba: Nagyalföldi Alapítvány, 2000.

[5] L. Somlyódy, Strategy of Hungarian water management (In Hungarian) Budapest: MTA Vízgazdálkodási Tudományos Kutató-csoportja, 2000.

[6] Gy. Várallyay, Main types of water regimes and substance regimes of Hungarian soils (In Hungarian) Agrokémia és Talajtan, Vol. 34, pp. 267–298, 1985

[7] Gy. Várallyay, Climate change and soil processes. Időjárás. Vol. 106, no. 3–4, pp. 113–121, 2002.

[8] Gy. Várallyay, Soil survey and soil monitoring in Hungary. In: Soil Resources of Europe.R. J. A. Jones, B. Housková, P. Bullock and L. Montanarella, Eds, pp. 169–179. ESB Research Report No. 9. (2nded.). Ispra: JRC, 2005.

[9] Gy. Várallyay, Soil degradation processes and extreme soil moisture regime as environmental problems in the Carpathian Basin. Agrokémia és Talajtan. Vol. 55, pp. 9–18, 2006.

[10] Gy. Várallyay, Extreme soil moisture regime as an increasing environmental problem in the Carpathian Basin. Tessedik Sámuel Főisk. Tudományos Közlemények. Vol. 7, no. 1, pp. 47–54, 2007.

[11] Gy. Várallyay, Soil degradation processes and extreme soil moisture regime as environmental problems in the Carpathian Basin. In: Scientific and Social-Institutional Aspect of Central Europe and USA. G. J. Halasi-Kun Ed, Vol. XXXVIII-XXXIX. Pollution and Water Resources, Columbia University Seminars Proceedings. pp. 181–208, 2009.

[12] Gy. Várallyay, Increasing importance of the water storage function of soils under climate change. Agrokémia és Talajtan, Vol.59, pp. 7–18. 2010.

[13] Gy. Várallyay, Soil water management as an important tool for environment protection in the Carpathian Basin. In: Proc. 3rd Int. Scientific Conference „Agriculture in nature and environment protection, Vukovar, 31 May-2 June, 2010. pp. 41–50.

[14] Gy. Várallyay, Environmental aspects of soil–water relationships in the Carpathian Basin. In: Pollution and Water Resources, J. Halasi-Kun, Ed., Columbia University Seminar Proc. Vol. XL. 2010–2011. Environmental Protection of Central Europe and USA. pp. 237–270. 2011.

[15] Gy. Várallyay, Soil degradation processes and extreme hydrological situations, as environmental problems in the Carpathian Basin. Acta Universitatis Sapiantiae, Agriculture and Environment. Vol. 3, pp. 45–67, 2011

[16] Gy. Várallyay, Water storage capacity of Hungarian soils. Agrokémia és Talajtan, Vol. 60. Suppl. (online) (ATON) pp. 7–26, 2011.

[17] Gy. Várallyay, Soil moisture regime as an important factor of soil fertility. Növénytermelés, Vol. 60. Suppl. pp. 297–300, 2013.

[18] Gy. Várallyay, Environmental aspects of soil management and moisture control. Proc. 6th International Scientific and Expert Conference TEAM 2014, Kecskemét, 10-11 Nov., 2014. 26-31.

[19] Gy. Várallyay, Multifunctionality of soil. 14th Alps-Adria Scientific Workshop, Neum, Bosnia and Herzegovina. Növénytermelés 64. Supp. 11-14. 2015.

[20] Gy. Várallyay and K. Rajkai, Model for the estimation of water and solute transport from the groundwater to the overlying soil horizons. Agrokémia és Talajtan, Vol. 38, pp. 641–656, 1989.

[21] Gy. Várallyay, L. Szücs, K. Rajkai, P. Zilahy and A. Murányi, Hydrophysical properties of Hungarian soils and the map of their categories in the scale of 1:100 000] (In Hungarian) Agrokémia és Talajtan, Vol. 29, pp. 77–112, 1980.