THE AGRO-CLIMATIC DROUGHT IN SLOVAKIA IN 2003

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Atmospheric precipitation is the main factor influencing the weather and climate of the area and is one of the main constituencies of water circulation in nature and water balance. Together with other meteorological elements they fundamentally creates the character of the area and makes the type of vegetative cover, river-basins conditions and productivity of the countries agriculture. They are typical for variability and casualty in quantity and quality and extent in time and place. They are ever changing and revolving natural water resources during times. Precipitation and other meteorological elements are the most important and much frequently used parameters which characterize climatic conditions of the followed area for realization not only water-economy projects but also for setting dimensional characteristics of water constructions for water management, also for agricultural on the irrigation requirements. The calculation itself is made by AFSIRS model, in which the referential evapotranspiration is calculated through Pennman-Monteith equation and the evapotranspiration of any crop under standard conditions is determined as a product of the referential evapotranspiration and so-called dimensionless crop coefficients. Not only intensity of transpiration, but also the non-inclusion of coefficients to be applied for individual irrigation devices must be taken into account when calculated values are applied in practical irrigation management.

Hodnotenie závažnosti sucha z pohľadu agroklimatického sucha sme spracovali netradičným spôsobom pre 15 lokalít Slovenska, od roku 1971 až pre rok 2003. Hodnotenie je založené na stanovení potreby závlahovej vody pre konkrétne plodiny, pričom uvádzame hodnotenie pre dva druhy plodín, intenzívny trávny porast a jablone. Vychádzame z predpokladu, že závlahovou dávkou sa upravuje vodný režim v pôde tak, aby rastliny netrpeli vodným stresom. Po výpočte potenciálnej evapotranspirácie metódou Penman-Monteitha sa ďalšie údaje spracovávajú programom AFSIRS. Výsledkom sú údaje o množstve závlahovej vody, potrebnej na udržanie zásoby pôdnej vody v rozmedzí medzi bodom zníženej dostupnosti a poľnou vodnou kapacitou. Táto metóda pomerne dobre reaguje ako na zvýšené transpiračné a evaporačné nároky spôsobené zvýšenou výsušnosťou okolitej atmosféry, tak aj na rozloženie zrážok, na nároky jednotlivých plodín na vodu v jednotlivých fenologických fázach, ale aj na pôdne vlastnosti vrátane zásoby vody v pôde z predchádzajúceho obdobia. Nesnažíme sa teda stanoviť množstvo vody, ktoré by v pôde chýbalo bez závlahy. Pretože ak sa znižuje zásoba pôdnej vody, vzrastá vodný stres rastliny a mení sa pomer potenciálnej a aktuálnej evapotranspirácie pričom za určitých situácií môže prísť k tomu, že zásoba vody v pôde už prakticky neklesá, pričom táto hranica je veľmi premenlivá.

Key words: Drought, AFSIRS model, precipitation, evapotraspiration, transpiration coefficient, irrigation requirement

INTRODUCTION

A relatively good overview of the situation in Slovakia in respect of 2003's precipitation total and their areal distribution and Slovakia has been provided by Faško et al. (2003), including the regime of stream-flow quantities in water courses at selected discharge gauging sites. Depending on the purposes of individual studies, the issue of drought may be considered from various aspects. When evaluating agro-climatic drought, not only precipitation totals, but also water requirements by individual crops in given time points, eventually soil water reserves and their dynamics shall be taken into account. In our climatic conditions periods of precipitation, bringing about increased water reserves in at least upper soil strata, use to occur commonly. It depends then on their frequency and intensity, eventually on a given crop, whether the periods of insufficient precipitation, preceding or following them are successfully overcome.

In the presented paper a not traditional way how to evaluate the seriousness of drought based on the determination of the irrigation requirements by concrete crops has been introduced. The adjustment of water regime through irrigation rates to prevent stress from drought has been the outgoing point of our consideration. The presented method responds relatively good both to increased transpiration or evaporation demands due to more intensive drying effect of the adjacent atmosphere and to the distribution and development of precipitation as well as the demands for water by individual crops in individual growth stages and the properties of soil, including soil water reserves from preceding period. Therefore our efforts were not aimed to determine the quantity of water, that would be missed in soil without irrigation, because decreasing soil water reserves result in higher stress from drought and shifting ratio of potential evapotranspiration and actual evapotranspiration, meanwhile under certain circumstances water reserves do not more decrease and this limit sometimes varies a lot.

DATA AND METHOD

In order to establish the respective demands for irrigation water by two selected crops in 2003, daily measuring of meteorological variables (precipitation, air temperature, air humidity, wind speed and duration of sunlight) in daily steps were required. The data were collected at 15 meteorological stations distributed throughout the territory of Slovakia (Table 1 and Figure 1). The aforementioned variables for the period 1971-2003 have been kindly provided for the purpose of the presented study by the Slovak Hydro-meteorological Institute (SHMÚ).

Table 1: List of the relevant meteorological stations

Name	Abbrev.	Elevation [m]	Latitude [°N]	Longitude [°E]	IV-IX precipitation total [mm]
Bratislava, let.	Br	131	48° 10	17° 12	305
Čaklov	Ca	133	48° 54	21° 38	429
Hurbanovo	Hu	115	47° 52	18° 12	307
Jaslovské Bohunice	JB	176	48° 29	17° 40	318
Košice	Ko	230	48° 40	21° 13	411
Kuchyňa	Ku	206	48° 24	17° 09	378
Milhostov	Ml	104	48° 40	21° 44	361
Oravská Lesná	OL	780	49° 22	19° 11	622
Piešťany	Pi	165	48° 37	17° 50	348
Rim. Sobota	RS	214	48° 22	20° 01	363
Sliač	Sl	313	48° 39	19° 08	386
Somotor	So	100	48° 24	21° 49	353
Telgárt	Te	901	48° 51	20° 11	551
Vígľaš	Vi	368	48° 33	19° 19	371
Žihárec	Zi	111	48° 04	17° 52	320

Figure 1. The relevant meteorological stations

Because of the reasons mentioned below intensive turf and apple tree were the two crops chosen for the purpose of the presented study:

- they can be found and are grown in the most of agriculturally exploited areas,
- they are of permanent nature with root systems not changing throughout the most of their cycles of vegetation,
- they differ in their rooting depths, transpiration coefficients and decreased availability points during their cycles of vegetation.

Intensive turf is considered representative for crops having their cycles of vegetation longer and root systems relatively shallow, resulting in limited water reserves and high transpiration demands throughout the entire cycles of vegetation.

On the contrary, apple tree have deeper root systems and their demands for water use to be higher only in several months of their cycles of vegetation.

For intensive turf and apple tree the depths of irrigated horizons were supposed 15 cm and 50 cm and the depths of rooting zones of 30 cm and 100 cm respectively. The soil profile was supposed to be homogeneous throughout the entire rooting zones, consisting of loamy soil with the normal field capacity value of 20% vol.

In course of the recent fifty years the world-wide development in the methods applied to calculate potential evapotranspiration has achieved its standard level in the equation by Penman as adjusted by Monteith, requiring meteorological variables measured at a relatively high number of stations as input data. The said equation serves to establish referential evapotranspiration values (mostly associated with intensive turf) pursuant to a code of practice by FAO and it is considered a general approach to the issue of evaporation.

Daily and other intervals are calculated from basic meteorological variables (air temperature, air humidity - expressed as water vapour pressure or relative humidity, duration of sunlight or global radiation, wind speed), while the remaining parameters use to be set separately to constant levels for individual intervals. Thus individual, different regions can be compared relatively good in this way.

The basic formula to calculate referential evapotranspiration of turf according by the full form of the Penmann-Monteith Equation, FAO method is as follows:

$$ET_o = \frac{0{,}408 * \Delta * (R_n - G) + \gamma * \dfrac{900}{T + 273{,}16} * u_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0{,}34 * u_2)} \qquad (1)$$

with ET_o referential evapotranspiration [mm.d^{-1}],
R_n radiation on a hypothetical surface, in fact its balance [MJ.m^{-2}.d^{-1}],
G heat flow in a soil [MJ.m^{-2}.d^{-1}],
T mean daily air temperature at 1.5 to 2.5m height [ºC],
u_2 wind speed in 2 m height [m.s^{-1}],
e_s saturated water vapour pressure at the temperature measured in a thermometer shelter [kPa],
e_a water vapour pressure calculated from the temperature measured in a thermometer shelter [kPa],
e_s - e_a saturation deficit [kPa],
Δ the slope of water-vapour curve at a given temperature, i.e. derivation of the association between the specific humidity of a water-vapour saturated air and its temperature [kPa.ºC^{-1}],
γ psychrometric constant [kPa.ºC^{-1}].

The fundamental significance of evapotranspiration established in this way is the possibility to use it when dealing with questions concerning actual evapotranspiration. The evapotranspiration of any crop under standard conditions can be calculated as a product of the referential evapotranspiration and a dimensionless, so-called "crop coefficient", the values of this latter have been assigned and empirically established to individual crops:

$$ET_c = K_c * ET_o \qquad (2)$$

with ET_c evapotranspiration [mm.d^{-1}],
K_c crop coefficient,
ET_o referential (potential) evapotranspiration [mm.d^{-1}].

Different K_c values use to be applied by authors world-wide, those in the presented paper are given in Table 2 (Allen, 1998).

Table 2: The crop coefficient (K_c) and normal field capacity (%VVK) values applied to two crops – intensive turf and apple trees

Crop		Month					
		V	VI	VII	VIII	IX	X
Apple trees	K_c	0.5	0.6	0.9	0.9	0.8	0.7
	% VVK	50	60	70	70	60	50
Intensive turf	K_c	0.85	0.78	0.78	0.82	0.83	0.83
	% VVK	60	60	60	60	60	60

Calculate the actual evapotranspiration of a given crop from the referential evapotranspiration reduced with the respective „crop coefficient" (K_c), expressing the relation between the actual evapotranspiration of the said stand and the calculated value of referential evapotranspiration representing turf - approximately 7 – 15 cm high having its K_c value equal to 1 (K_c = 1). Whereas intensive turf – usually showy laws use to be mown frequently to a height of 5 cm, their K_c value shall be reduced. The coefficients applied to the calculation, together with respective decreased availability values (*%VVK*) are given in Table 1. Regarding that irrigation is launched by the application programme as soon as the decreased availability point has been achieved, no reduction of evapotranspiration owing to water insufficiency is supposed and therefore no other coefficient (stress coefficient – K_s) needs to be introduced. Thus the actual evapotranspiration of a given stand is always equal to the potential one.

With the values of crop coefficient (K_c) and required meteorological variables known soil water balance can be made and the irrigation rate necessary to keep soil water reserves between the points of decreased availability and normal field capacity, established.

We have applied the Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) model (Smajstrla, 1990), which simulates in daily steps a set of dynamic processes, encompassing infiltration, re-distribution and extraction of water by plants. The said application allows to calculate the balance of soil water in two strata, designated as "irrigated" and "non-irrigated". A 70% share of water from its overall quantity in the irrigated stratum, constituting almost one half of the soil profile, is used by the crop for transpiration and may increase accordingly to reduced water reserves in the lower stratum during longer periods of drought. Under normal conditions the share of water from the lower stratum used by crop for transpiration is only 30 %. Under extreme conditions water may be extracted from the irrigated stratum only.

The calculation is made on a daily basis whereby the quantities of water used for transpiration by the crop are determined and subtracted from water reserves in the both strata. Once the water reserves in the lower stratum are exhausted, water is taken from the upper stratum as long as the decreased availability point (Θ_{BZD}) is achieved. The decreased availability point (Θ_{BZD}) has been established as the value of normal field capacity *(%* Θ_{VVK}) for a given soil and a given crop in course vegetation period. Irrigation rate value can either be user selected or be calculated by the application. In the latter case such irrigation rate is delivered that is sufficient to saturate the upper stratum up to its normal field capacity (Θ_{PVK}). Optionally water reserves can be replenished to achieve a set *%* Θ_{VVK} value and irrigation is then operated under certain water deficit. In the event of more abundant precipitation leading to the saturation of both strata, either seepage to outside the active zone or surface run-off occur and the reserves of water in soil no more increase. The precipitation in course of the whole year use to saturate the upper stratum first, then the lower one and after the both strata having been saturated, further precipitation use to be designated seepage. The statistical part of the application allows to evaluate not only the mean values of individual variables for a given assessed period, but also the required irrigation rates with certain periodicity of occurrence in accordance with Weibull distribution, particularly with lower frequency.

The AFSIRS model has been intended to process multi-annual sets of daily potential evapotranspiration and precipitation data and it also comprises sub-applications to calculate not only basic statistical characteristics, but also surpass curves of monthly and yearly precipitation totals using Weibull distribution. Apart from the above, daily values of water reserves in individual strata, seepage of precipitation, potential and actual evapotranspiration can be produced. These data are suitable to follow the entire course of calculation detailedly. An example how the balance of soil water reserves can be made using AFSIRS application is illustrated for 2003 on the cases of intensive turf at Oravská Lesná and apple trees in this region (Figure 2 and Figure 3 respectively). The need to irrigate the intensive turf stand was minimum and the apple trees did not need any irrigation at all.

RESULTS AND DISCUSSION

The output from the above processing are the data on the quantity of irrigation water required to keep soil water reserves values between the points of decreased availability and normal field capacity. The ASFIRS methods provides data on the value of required irrigation water quantity, wherefrom the course of a complete cycle of vegetation may be traced.

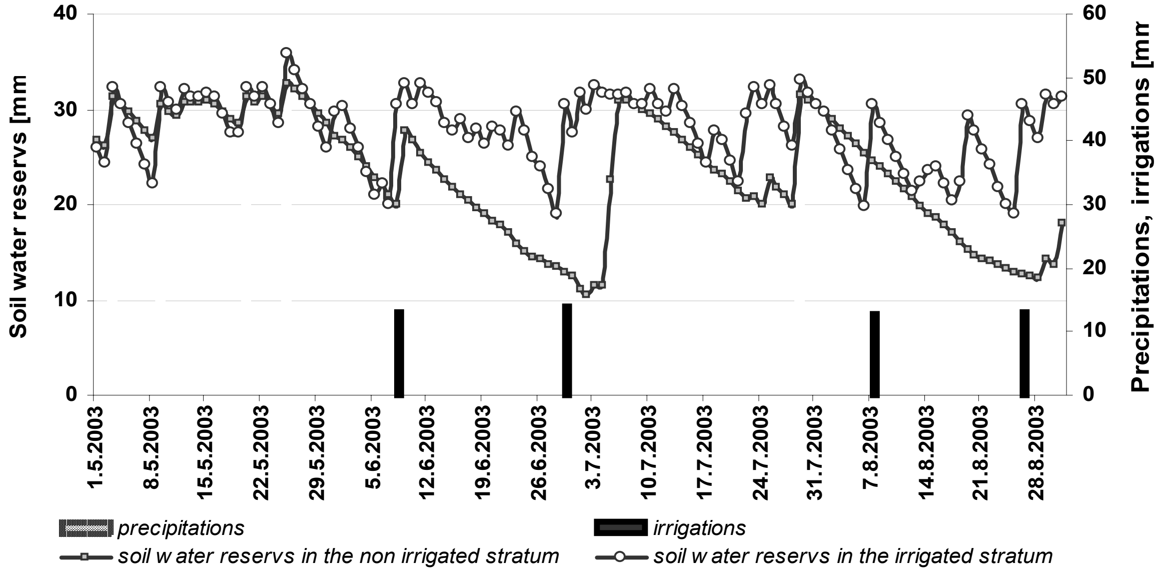

Figure 2. The calculated soil water reserves beneath an intensive turf in Oravská Lesná (2003)

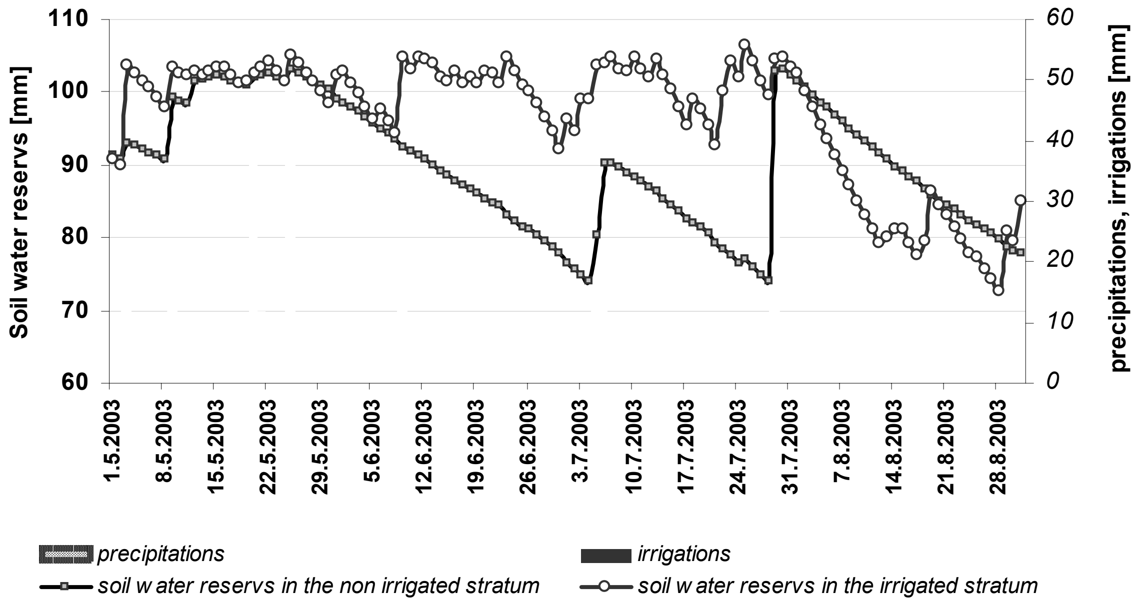

Figure 3. The calculated soil water reserves beneath apple tree in Oravská Lesná (2003)

We have compared the calculated quantities of irrigation water for both crops and the relevant stations with the average irrigation requirement from the 1971-2000 period and at the same time expressed the deviation from the average value as a multifold of the standard deviation (Figure 4). Relative values of the required quantity of irrigation water in relation to its average values from the 1971-2000 period are given on Figure 5.

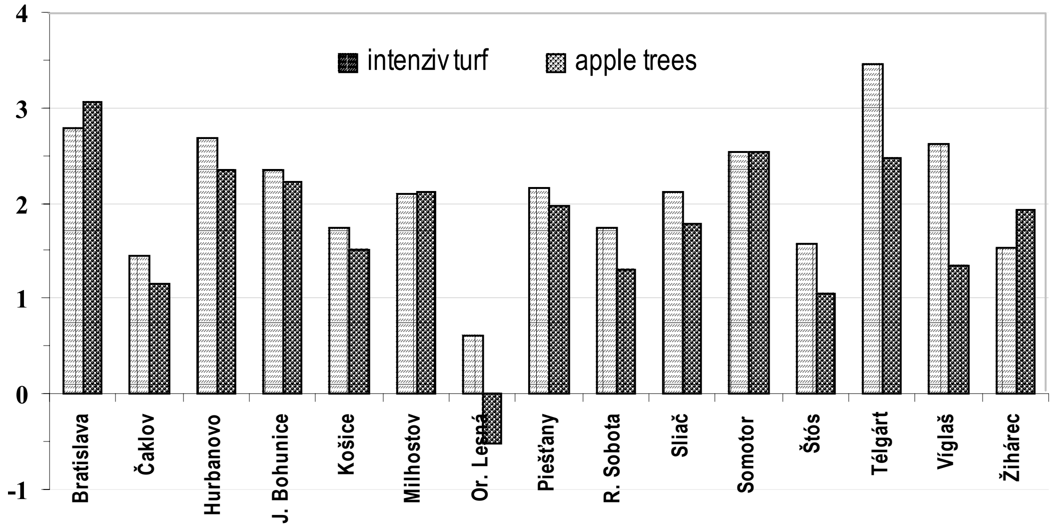

Figure 4. The difference between the required quantity of irrigation water in 2003 and the average value expressed as standard deviation multifolds

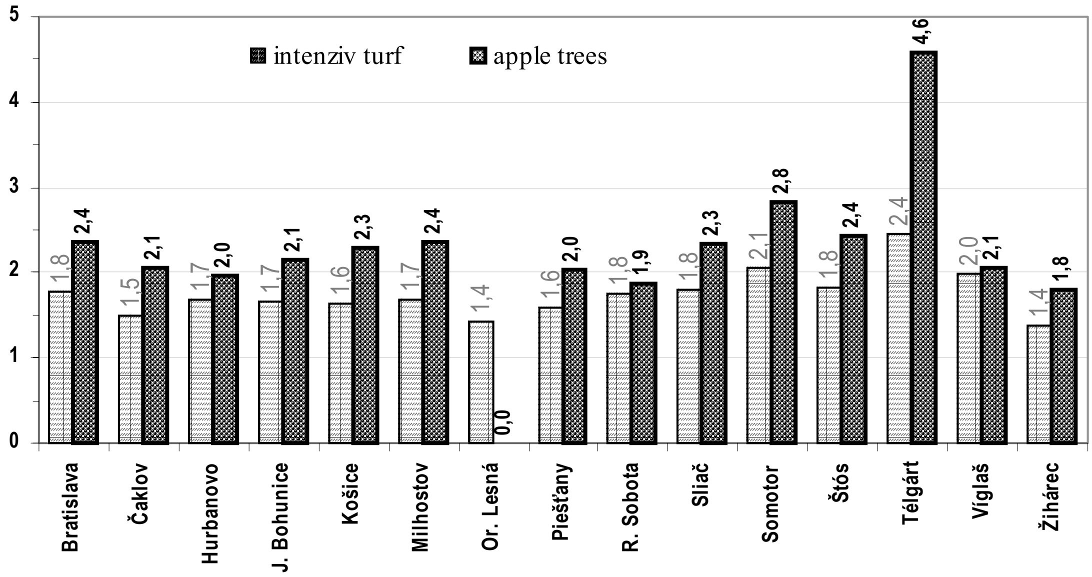

Figure 5. A relative value of the required quantity of irrigation water in relation to its average value for the period 1971-2000.

Apart from the aforementioned we have determined the positions of the 2003's irrigation requirements value in the descending order of these values since 1971.

Table 3. The calculated values of irrigation requirements and their characteristics

Station	Average 1971-2000 $\bar{x}$ [mm]	Standard deviation from average 1971-2000 s [mm]	M_z (2003) x_{2003} [mm]	$x_{2003}/\bar{x}$	$(x_{2003} - \bar{x})/s$	Position of 2003's value
	Intensive turf					
Bratislava	210	58	371	1.8	2.8	1
Čaklov	101	34	150	1.5	1.5	3
Hurbanovo	213	54	358	1.7	2.7	1
Jaslovské Bohunice	211	59	348	1.7	2.3	1
Košice	150	55	246	1.6	1.7	3
Milhostov	145	48	246	1.7	2.1	1
Oravská Lesná	37	26	53	1.4	0.6	9
Piešťany	189	52	302	1.6	2.2	2
Rimavská Sobota	147	63	257	1.8	1.7	4
Sliač	129	49	234	1.8	2.1	1
Somotor	152	63	312	2.1	2.5	1
Štós	92	48	167	1.8	1.6	2
Telgart	65	27	160	2.4	3.4	1
Víglaš	122	46	244	2.0	2.6	2
Žiharec	188	46	259	1.4	1.5	3
	Apple trees					
Bratislava	117	52	277	2.4	3.1	1
Čaklov	32	29	66	2.1	1.2	4
Hurbanovo	126	52	246	2.0	2.3	1
Jaslovské Bohunice	117	60	251	2.1	2.2	1
Košice	61	52	140	2.3	1.5	3
Milhostov	60	39	142	2.4	2.1	2
Oravská Lesná	8	16	0	0.0	-0.5	
Piešťany	103	53	208	2.0	2.0	1
Rimavská Sobota	75	50	140	1.9	1.3	4
Sliač	62	46	145	2.3	1.8	3
Somotor	73	53	206	2.8	2.5	1
Štós	27	37	66	2.4	1.0	3
Telg8rt	14	20	63	4.6	2.5	2
Vígľaš	52	41	107	2.1	1.3	3
Žihárec	100	41	180	1.8	1.9	1

The calculated characteristics of 2003's irrigation requirements and their comparison with the period of 1971 – 2000 are given in Table 3.

The ratio between 2003's irrigation requirements and their long-term average (Figure 5) varied between 1.5 and 2.5 with the exception of Telgárt, where its high value is owing to the average's low value. Higher average's values have been found for apple tree indicating thus decreasing water reserves also in deeper soil strata. Only for Oravská Lesná the distribution of precipitation was such that no need of irrigation arose (Figure 3). A better imagination about extreme nature of the relevant period in individual regions of Slovakia can provide Figure 5 with its data on the difference between the 2003's irrigation requirement and the average expressed as a multifold of the standard deviation.

In accordance with the data published by Nosko (1972), provided this value varies within the ranges 1 to 2, 2 to 3 and above 3, the phenomenon can be considered beyond, strongly beyond and extremely beyond the normal, respectively. In the light of this evaluation the extremeness of drought is the most obvious in Bratislava, while Telgárt may have been strongly influenced by a low value of the average. Less extreme are the manifestation of drought from Víglaš through Rimavská Sobota and Košice as far as Čaklov. On the contrary the easternmost and westernmost parts of Slovakia belong to those very dry. Such distribution corresponds also to the characteristics set by the order of 2003's positions in respect of moistening irrigation requirements since 1971, as given in Table 3. In the recent 33 years the year 2003 belonged to the driest at almost one half of the relevant stations, meanwhile on the remaining stations the years 2000 or 1992 have shown to be drier.

CONCLUSIONS

The application of the presented method has indicated, that the extremeness of the drought in 2003 was the most obvious as in Východoslovenská nížina lowland as in a larger Podunajská nížina lowland, where the 2003's drought has been evaluated as the worst in the recent 33 years. Though between them - in a more hilly part of the Slovak territory - the said drought in respect of irrigation requirements and a long-term viewpoint the drought has shown itself to be less extreme, whereas even drier years occurred in the past, in most cases 2000 or 1992 have been referred to.

The weather extremes of the most recent year indicate the necessity to support the operation of irrigation systems that still are in good, operable condition and to adapt their modernisation to actual economic conditions, whose features prevailingly are the optimation of irrigation systems, irrigation devices of higher standard, smaller areas of individual farms and shifts in the assortment of irrigated crops. However, if in the future drier years are to be more numerous and manifested on vast regions of our continent, also irrigation of such crops as cereals or fodder crops, whose shares among irrigated crops once were of up to 60 %, will become economically interesting.

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