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Drought analysis of agricultural regions as influenced by climatic conditions in the Slovak Republic

Bernard Šiška[1*] and **Jozef Takáč**[2]

[1]*Department of Biometeorology and Hydrology, Slovak University of Agriculture in Nitra, Please give the postal address. SK; E-mail:* bernard.siska@uniag.sk
[2]*Soil Science and Conservation Research Institute, Please give the postal address Bratislava, SK; E-mail:* takac@vupu.sk

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Abstract—Drought analysis of the Slovak territorry was based on evaluation of climatic conditions during the growing season limited by daily mean air temperature T >10 °C. Precipitation total (R in mm), and potential (E_0 in mm) and actual (E in mm) evapotranspiration were calculated for this period. Consequently, climatic index of drought ($E_0 - R$) and evapotranspiration deficits ($E_0 - E$) were evaluated on the background of agricultural productive regions. Climatic data from the database of the Slovak Hydrometeorological Institute in Bratislava in period of years 1960–1990 were used for evaluating the reference climate condition. Climatic stations used for GIS analyses were selected from the point of view of altitude, limiting plant production areas (up to 900 m a.s.l. – this altitude represents acreage 45,000 km^2) and spatial distribution. Climate change conditions were generated by general circulation model CCCM for emission scenario SRES B2.

According to the results, agricultural regions of the Slovak Republic will become more sensitive in conditions of climate change on drought occurrence as compared with climate conditions of the last normal period 1961–1990. While 5 categories of drought conditions were recognized on the territory of the Slovak Republic in the reference period 1961–1990, additional two very dry categories can be recognized in agricultural regions of Slovakia according to climatic indices of both drought and evapotranspiration deficit. This fact has serious effects on potential acreage of some crops. High totals of potential evapotranspiration can evoke occurrence of drought more frequently. This fact should be taken into account in the future on the levels of both crop selections and water saving rotations.

Key-words: climatic index of drought, evapotranspiration deficit, precipitation, drought, growing season, Slovakia

[*] Corresponding author

1. Introduction

Climatic conditions become the most important factor influencing variability of field crop yields in Slovakia today. Increase of annual mean air temperature by about 1 °C was occurred on most of climatic stations in Slovakia during last century. On the other hand, annual precipitations decreased by about 10% on lowlands of Slovakia (Danubian and east Slovakian lowlands) during this period. Precipitation totals varied also in mountainous regions, but no significant trend was found during last century (*Lapin et al.*, 2001). Increase of air temperature and shortage of precipitations create also conditions for drought occurrence, especially on lowlands of Slovakia. According to the outputs of the general circulation models (GCM), this trend is also supposed for future climate. Those facts call for analysis of drought occurrence in conditions of climate change on territory of the Slovak Republic.

According to the natural climate variability and the duration of drought, several levels of drought can be defined (*Hayes et al.*, 1999; *Heim*, 2002). For example, the difference between potential evapotranspiration and precipitation totals during growing season limited by mean air temperature $T \geq 10$ °C was defined as climatic index of drought for conditions of Central Europe. This index was frequently used in many works for evaluation of drought conditions (*Ditmarová et al*., 2006; *Dubrovský et al*., 2005; *Hlásný* and *Baláž*, 2008; *Tomlain*, 1997; *Trnka et al*., 2007). This index was also used for agroclimatic regionalization of the Slovak Republic during the periods of 1931–1960 (*Kurpelová, et al.*, 1975) and 1961–1990 (*Šiška* and *Špánik*, 2008).

Evapotranspiration, as an important component of water balance, is also frequently used for evaluation of drought conditions in Slovakia. Spatial distribution of potential evapotranspiration was related to water needs of ecosystems (*Tomlain*, 1979; *Škvarenina et al*., 2008), actual evapotranspiration was correlated to yield of some field crops (*Matejka* and *Huzulák*, 1995; *Vidovič* and *Novák*, 1987). Difference between potential and actual evapotranspiration defined as evapotranspiration deficit can be a good parameter for evaluating the drought condition of the landscape on agricultural level.

The aim of the paper is to evaluate drought occurrence in climate change conditions by means of GIS in Slovakia.

2. Material and methods

Climatic data from the database of the Slovak Hydrometeorological Institute (SHMI) in Bratislava were used for calculation of present climate ($1\times CO_2$) in this paper. Climatic stations used for GIS analyses were selected with respect to agricultural productive types, altitude (up to 900 m a.s.l. – upper range of plant production), and spatial distribution. Evaluated acreage represents 45,000 km^2 –

90% of total area of Slovakia. Climatic data of the period 1961–1990 for 11 stations given in *Table 1* were used. These climatic stations represent 4 Slovak agroclimatic regions (productivity types).

Table 1. Agricultural regions and related climatic stations

Agricultural regions (productive type)	**Altitude (m a.s.l.)**	**Climatic stations**	**Altitude (m a.s.l.)**
Maize	< 200	Somotor	100
		Hurbanovo	115
		Nitra	143
		Piešťany	165
		Kamenica n/C.	178
Sugar beet	200 – 300	Rimavská Sobota	214
		Prievidza	260
		Košice	230
Potato	300 – 500	Bardejov	304
		Sliač	330
Mountainous	>500	Liptovský Hrádok	640

Temperature and drought characteristics were evaluated for growing seasons limited by daily mean air temperatures T >10.0 °C, henceforth signed by GS10. Daily mean air temperature sums (TS in °C), precipitation totals (R in mm), potential evapotranspiration (E_0 in mm), and climatic index of drought ($E_0 - R$ in mm) were calculated for GS10. Potential (E_0) and actual (E) evapotranspiration were calculated according to Budyko-Zubenok method (cit. in *Tomlain*, 1979).

In this study, two indices were selected for spatial evaluation of drought conditions for the territory of Slovakia: the climatic indices of drought and evapotranspiration deficit.

Since drought conditions are frequently observed during the whole growing season, calculation was applied for the whole growing season (GS10 period).

Climatic index of drought was calculated as:

$$K_{GS10} = E_0 - R, \tag{1}$$

where E_0 is the potential evapotranspiration during GS10 and R is the rainfall during GS10.

Evapotranspiration deficit was calculated as:

$$\Delta E_{GS10} = E_0 - E, \tag{2}$$

where E_0 is the potential evapotranspiration during GS10, and E is the actual evapotranspiration during GS10.

Onset and end of GS10 were established according to numeric analyses (*Nosek*, 1972). GS10 is limited by biological temperature minimum of thermophil plants (by daily mean air temperature of $T \geq 10.0$ °C).

A raster model of geodata was applied for the spatial evaluation of the climatic parameters. Through the interpolation, the spatial change of the individual average meteodata was calculated. The method of regularized spline interpolation with tension and kriging was applied. Global radiation, air mean temperature, and precipitation for 2×CO_2 climate were generated by general circulation model CCCM 2000 (*Lapin et al.*, 2001). Consequently, potential and actual evapotranspirations were calculated.

Finally, by comparing the spatial distribution of the climatic indices of drought and evapotranspiration deficit for 1×CO_2 and 2×CO_2 scenarios, climate sensitivity of the agricultural regions of Slovakia to drought occurrence was evaluated.

3. Results

3.1. Duration of growing season

The main growing season (GS10) is limited by the onset and end of daily mean air temperature $T > 10$ °C, and it is the period when drought conditions are frequently observed.

The onset and end of GS10 in altitudinal profile of Slovakia are given in *Fig. 1*. As resulted from trend lines of the onset and end of GS10, the onset of GS10 would start significantly earlier by about 28 days in climate conditions of the 2×CO_2 climate in the whole altitudinal profile as compared to climate conditions of the 1×CO_2 climate. The end of the GS10 period will be delayed by about 14 days under the 2×CO_2 climatic conditions as compared to the 1×CO_2 climatic conditions.

The duration of the GS10 of the maize region related to the reference period 1×CO_2 is 175 days or which represents about 34% of total acreage of agricultural regions. Those conditions will occur on 80% of the total agricultural regions acreage in 2×CO_2 climatic conditions and the duration of GS10 can exceed 200 days in the Danubian lowland, east Slovakian lowland, and Zahorie lowland. Duration of GS10 influences positively photosythetically active period of maize and, therefore, also biomass creation. On the other hand, a longer duration of GS10 also increases the potential risk for drought occurrence.

3.2. Precipitation (R)

Generally it is supposed, that the precipitation total increases in 2×CO_2 climatic conditions. Except for the GCM (CCCM 2000), this fact is influenced also by a rising duration of GS10. An increase of *R* by about 60 mm in the lowlands of southern and eastern Slovakia and by 79–134 mm in northern Slovakia will probably not be sufficient. All regions should receive more than 390 mm precipitation during GS10 in 2×CO_2 climatic conditions, and a raising rainfall could favorably influence the yield of some crops (e.g., maize and other cereals). The distribution of precipitation generated by the GCM in the context of rising air temperatures and consequently increasing crop water demands during GS10 will, however, very probably result in increasing occurrence of drought conditions reducing yields of field crops.

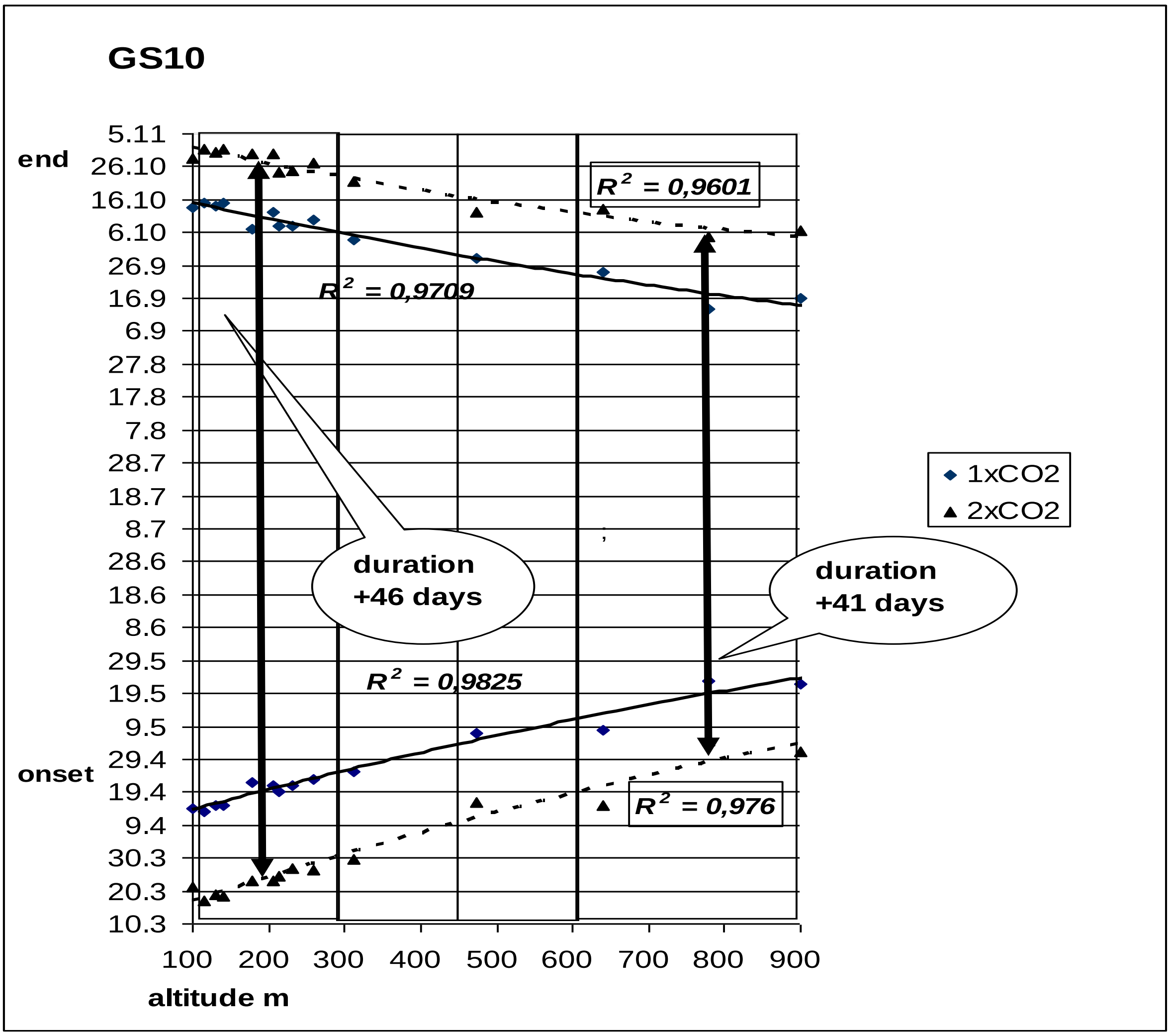

Fig. 1. Onset and end of growing seasons GS10 in dependence on altitude for 1×CO_2 and 2×CO_2 climates.

3.3. Changes of evapotranspiration characteristics

Evapotranspiration as a significant element of environmental water balance is a suitable indicator for moisture balance in any space and time scale. While potential evapotranspiration can be used as an indicator for estimating of water demand of the maximum productivity of ecosystems (*Šiška*, 1992), the exact estimation of actual evapotranspiration can lead to an actual assessment of biomass production (*Vidovič* and *Novák*, 1987).

Our study shows that potential evapotranspiration of $E_0 > 450$ mm during the GS10 period in the whole agricultural area, and even E_0 exceeding 700 mm, can be expected in the warmest areas of Slovakia (south of Danubian lowland, and the lowest areas of east Slovakian lowland). Such high E_0 totals call for the need of effective management with water resources and for building irrigation systems in most of the territory of Slovakia to eliminate negative effects on yield production.

3.4. Climatic index of drought

Climatic index of drought (K) was applied for the first time as index of agroclimatic regionalization of Slovakia by *Kurpelová et al*. (1975). The difference between potential evapotranspiration and precipitation during summer months was taken into account. Because drought conditions are frequently observed during the whole growing season, K was recalculated for the whole GS10 period (*Šiška* and *Špánik*, 2008).

The supposed air temperature increase and consequent increase of GS10 duration influence the E_0 increase in the $2\times CO_2$ climate on the whole area of Slovakia. During GS10, E_0 will increase in the lowlands of Slovakia by 160 – 170 mm, i.e., by 27–30%, on uplands by 106 mm, i.e., by 34%. E_0 >500 mm can be expected in all agricultural regions of Slovakia, E_0 >750 mm can be expected in the warmest regions of Slovakia (south of Danubian lowland and east Slovakian lowland). Such high E_0 totals during the relatively short GS10 period (compared to GS5) will increase the potential of the occurrence of drought periods. Effective management of water resources can, therefore, eliminate the negative influences of evaporation demand on agricultural production in the majority of regions in Slovakia.

K_{GS10} is changing in the whole altitudinal profile of Slovakia significantly. The original classification scale of drought-wet conditions proposed by *Kurpelová et al*. (1975) was based on 50 mm differences of the index. According to this criterion, 5 categories of drought conditions can be defined for the reference ($1\times CO_2$) climate. Most of the agricultural acreage belongs to the areas where wet conditions prevail in altitudes above 550 m. According to the calculations based on CCCM outputs, those conditions can be found in future in altitudes higher than 700 m. Other two categories of drought can be defined, where the deficit of water exceed 250 mm during GS10 (*Fig. 2*). These two new categories of drought will cover the most productive regions of the Slovak Republic – the Danubian and east Slovakian lowlands that represent the maize region productive type.

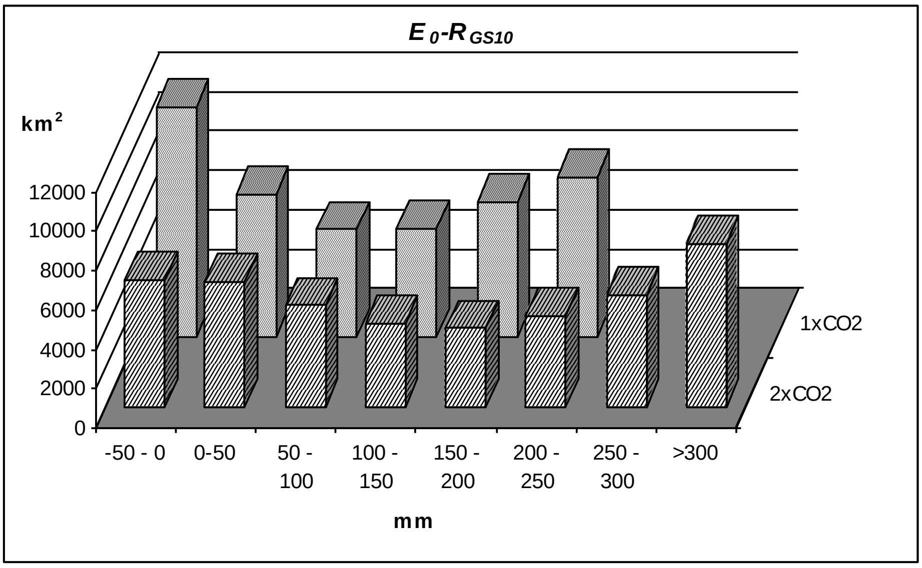

Fig. 2. Spatial distribution of climatic index of drought (*K*) during GS10 for 1×CO_2 and 2×CO_2 climates in Slovakia.

3.5. Evapotranspiration deficit

Evapotranspiration deficit ΔE as an important compound of water balance was also used for evaluation of drought conditions in Czechoslovakia (*Tomlain*, 1979). Except for meteorological factors, the calculation of actual evapotranspiration takes into account also soil water content and therefore, this parameter can better reflect drought conditions of agricultural regions.

According to the index ΔE, the territory of Slovakia looks even more vulnerable to drought than according to the previous index *K*. While $\Delta E \leq 100$ mm was calculated for sites with altitude over 300 m for the reference climate 1×CO_2, those conditions will be found in altitudes above 500 m for the 2×CO_2 climate (*Table 2*). These values represent potato and mountainous productive regions.

Table 2. Climatic index of drought ($E_0 - R$) and evapotranspiration deficit ($E_0 - E$) related to agricultural productive regions for 1×CO_2 and 2×CO_2 climates in Slovakia

Agro regions	**$E_0 - R$ [mm]**		**$E_0 - E$ [mm]**	
	1×CO_2	**2×CO_2**	**1×CO_2**	**2×CO_2**
Maize	150 – 250	250 – 360	130 – 220	240 – 350
Sugar beet	75 – 150	150 – 250	70 – 130	140 – 240
Potato	0 – 75	–20 – 150	30 – 70	90 – 140
Mountainous	< 0	< –20	<30	<90

The classification scale of drought-wet conditions of this index is also based on 50 mm differences. According to this criterion, 5 categories of drought conditions can be defined for the reference (1×CO_2) climate. As resulted from calculations based on CCCM outputs, two new very dry categories of drought can be introduced, where $\Delta E \geq 250$ mm (*Fig. 3*). Except for the Danubian and east Slovakian lowlands, these two categories of drought will cover also valleys of Slovakian rivers up to altitudes of 300 m. On the other hand, the acreage of agricultural regions, where $\Delta E < 50$ mm, will diminish under conditions of climate change.

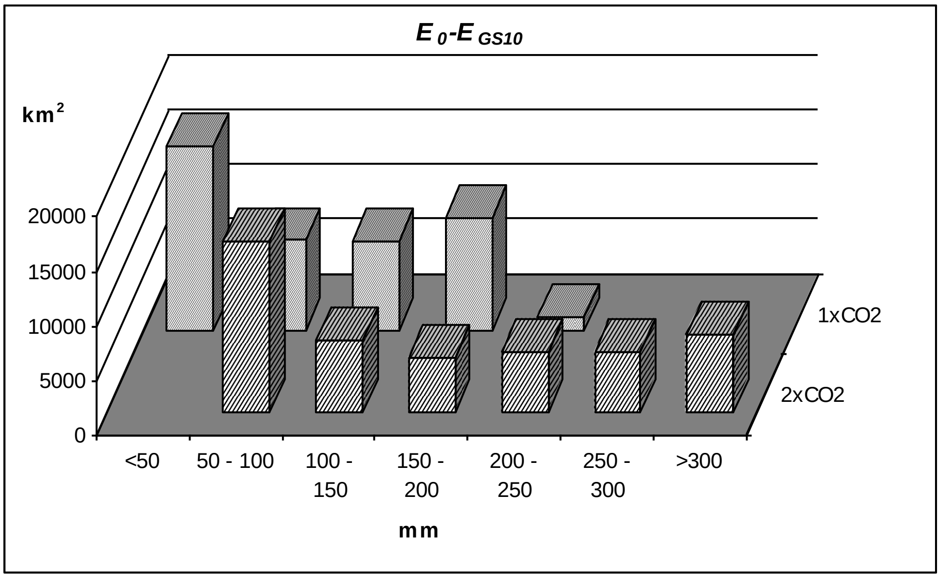

Fig. 3. Spatial distribution of evapotraspiration deficit ($E_0 - E$) during GS10 for 1xCO_2 and 2×CO_2 climates in Slovakia.

4. Conclusions

Drought conditions of agricultural regions were analyzed by climatic (climatic index of drought) and agroclimatic (evapotranspiration deficit) indices for the Slovak Republic.

It was found that the duration of the growing period (GS10) influences also the potential for drought occurrence.

According to both indices, two very dry and hot regions can be classified where the deficit of water exceed 250 mm. These two categories of drought will cover the most productive regions of the Slovak Republic – the Danubian and east Slovakian lowlands that represents the maize productive areas.

According to the evapotranspiration deficit, the agricultural regions of the Slovak Republic are more vulnerable under conditions of the applied climate change scenario as compared with *K*. $\Delta E \geq 250$ mm, except for Danubian and east Slovakian lowlands, will probably be recorded also in valleys of rivers up to altitudes of 300 m. Agricultural regions, where $\Delta E < 50$ mm, will probably disappear under conditions of this climate scenario in Slovakia.

According to K_{GS10}, most of the agricultural acreage belongs to areas where wet conditions prevail in altitudes above 550 m a.s.l. in the 1×CO_2 reference climate. As resulted from calculations based on CCCM outputs, those conditions will be found in altitudes higher than 700 m.

Except for agroclimatic planning issues, this facts should be taken into account in breeding strategies of new crop varieties suitable for the future climate of Slovakia.

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