SPATIAL PATTERNS OF AGRICULTURAL DROUGHT EVENTS IN DANUBE LOWLAND IN THE 1961-2013 PERIOD

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In the paper we present assessment of drought severity in Danube Lowland in the years 1961-2013 which is based on results of the soil water dynamics simulation by agro-ecological model Daisy. We did simulations for five different soil types in each of four pre-selected sub-regions characterised by daily meteorological data (1961–2013) from four corresponding meteorological stations. We used standardized index based on daily available soil water for subsequent classification of drought severity. Criteria set for the drought occurrence were 1) available soil water content below 50 % of available water capacity; 2) soil water content below long-term average soil water content and 3) duration of drought for fifteen or more consecutive days. We took normal climate period 1961–1990 as a reference period for analysing the drought severity and climate change impacts. Cumulative sum of available soil water index was used for quantifying the drought duration over the year. Geographical soil data used in simulations allowed us to analyse also the spatial pattern of the drought severity. Extreme drought of the largest spatial extent was identified in the years 1990, 1978, and 2012. Occurrence and duration of drought events increased in the last two decades and as the most vulnerable soils in the region Chernozems and Luvisols.

Keywords: available soil water, drought, soil type

INTRODUCTION

An adequate supply of water is an important perquisite for sustaining constantly high crop productivity. Under rainfed conditions this is significantly limited by sufficient amount of the water in the soil. Soil water availability varies from year to year depending on the weather conditions. Drought, i.e. a negative deviation from the normal water balance in given area (Brázdil et al., 2009), occurs with varying frequency, severity, duration and spatial extent, and is considered to be a natural phenomenon in most areas across the Europe.

In European context, central Europe and namely Slovakia is not considered an area prone to droughts occurrence, but climate observations show that local or regional droughts occur more often in recent decades even there (MoE SR & SHMI, 2013). Two bread-basket regions of Slovakia – *Podunajská nížina* and *Východoslovenská nížina* lowlands have been identified as very dry regions according to selected climatic and agro-climatic indicators (Šiška & Takáč, 2009). Declining trend of soil water content and progressive extension of the drought duration in the *Žitný ostrov* lowland region has also been shown by water balance simulations in the period of 1971-1994 (Takáč, 1999). In the future we can expect that the climate change and increased water demand driven drought vulnerability of crop production in Slovakia will be higher. According to the climate change scenarios we also can expect that average soil water content will gradually decrease (Takáč, 2001), and potential yields will be increasingly limited in the lowlands due to decreasing water availability for crops and heat waves occurrence (Eitzinger et al, 2012).

Important question related to any drought study is how to quantify abnormality, i.e. the shift from drought duration and/or severity typical for the particular area. Quantitative agro-climatic indicators were successfully applied in the study of Takáč (2013) for agronomic drought abnormality evaluation in conditions of Slovakia.

In our study we apply above algorithm in one of the most agricultural productive area of Slovakia (Danube lowland) together with spatial data on long-term (1961-2013) soil water balance calculated by Daisy model. Our goal is to analyze if consideration of different soil types in the soil water-balance calculations has an impact on spatial estimates of agricultural drought abnormality.

MATERIALS AND METHODS

Study area

Danube lowland (further referred to as study area) is situated north of Danube in the SW part of Slovakia (Fig. 1). Study area is warm (mean annual temperature range 9 to 10 °C) and dry (annual precipitation range 500 to 550 mm) with mild winter (mean temperature in January range -1 to -2 °C) and mean temperature in July range 18 to 21 °C. Major soil types occurring in the study area are *Chernozems* (47 %), *Luvisols* (22 %), *Fluvisols* (15 %) and *Phaeozems* (14 %). Study area is used mostly for crop production with total cropland area 672000 ha. Winter wheat, spring barley, maize, winter rape, sunflower and sugar beet are most important crops for the study area.

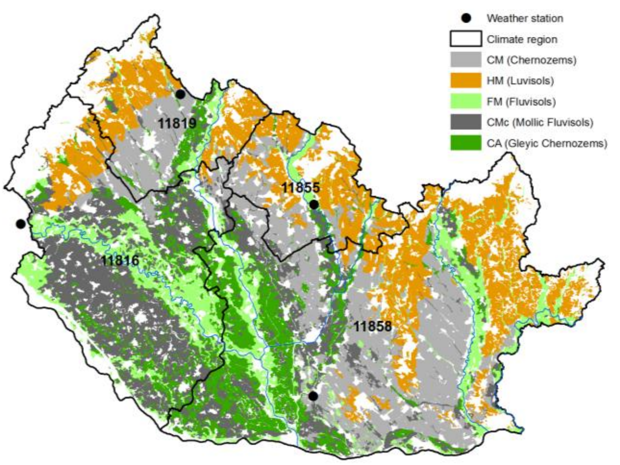

Fig. 1 Study area – climate regions, soil types and location of weather stations

Long-term soil water balance calculation

We did all soil water dynamics simulations with agro-ecological model Daisy (Abrahamsen & Hansen 2000; Hansen *et al*. 1990) well performing in different conditions (e.g. Palusao et al. 2011; Rötter et al. 2012). Daisy model can simulate crop production and water balance in daily step over many years taking into account climate, soil, and topography conditions and real crop management.

We used daily data on mean, maximum and minimum air temperature, air humidity, global radiation, wind speed and precipitation for the period of 1961 to 2013 from four weather stations (11816 – *Bratislava*, 11819 – *Jaslovské Bohunice*, 11855 – *Nitra*, and 11858 – *Hurbanovo*; Fig. 1) and extrapolated point data into four climatic regions corresponding to dissolved NUTS3 region boundaries (Fig. 1).

From the existing soil soil map we have identified five dominant soil types for the study area (Linkeš et al. 1996): *Chernozems* (CM), *Luvisols* (HM), *Fluvisols* (FM), *Mollic Fluvisols* (CMc), and *Gleyic Chernozems* (CA), Fig. 1. We took soil profile data on texture and humus content for each soil type from national soil profile database (Linkeš et al. 1988) and estimated all missing soil hydrological parameters (retention curve parameters, saturated hydraulic conductivity) with pedo-transfer function (HYPRES, Wösten et al. 1999) up to 1m depth.

As an expert-based rule, we set the groundwater table depth to 150 cm (CA) or 200 cm (FM, CMc); we have not considered any groundwater influence for CM and HM.

We have run simulations for winter wheat, spring barley, and maize; having each crop simulated in each year during the period of 1961 - 2013. We set crop parameters optimized for conditions of Slovakia (Takáč & Šiška 2011) for all simulations.

Drought abnormality quantification

We have used algorithm published by Takáč (2013) which compares daily data on available soil water content (*ASWC*, [mm]) to long-term average for the given day (normal period 1961 – 1990 in our case) with standardized available soil water index (*ASWI*).

We calculated *ASWI* from daily soil water balance outputs of the Daisy model as

$$ASWI = \frac{ASWC - ASWC_{AVE}}{ASWC_{SD}}$$

where $ASWC_{AVE}$ is long term average and $ASWC_{SD}$ is standard deviation of the long-term actual soil water content [mm] (Takáč 2013).

Tab. 1 Drought severity classes based on the cumulative available soil water index ($ASWI_{CUM}$), Takáč 2013

Drought class	Prob. interval [%]	$ASWI_{CUM}$ [–]
Extreme	≤ 2 %	≤ -300
Severe	2 % to 10 %	-299 to -200
Moderate	10.1 % to 25 %	-199 to -100
Normal	25.1 % to 50 %	-99 to 0

To get drought abnormality data on yearly basis we identified periods of drought occurrence as periods of at least 15 consecutive abnormally dry days (days with *ASWC* value less than 50 % of potential plant available water capacity and negative value of *ASWI*). As a quantitative measure of drought abnormality we have used number of abnormally dry days occurring in all drought periods during the particular year and cumulative sum of *ASWI* ($ASWI_{CUM}$) of all abnormally dry days occurring in all drought periods during the particular year (Tab. 1).

RESULTS

Results on occurrence, duration, and severity of abnormal drought is different in dependence on the on the soil type as well as climate region are summarised on Fig. 2, Fig. 3, and Tab. 3.

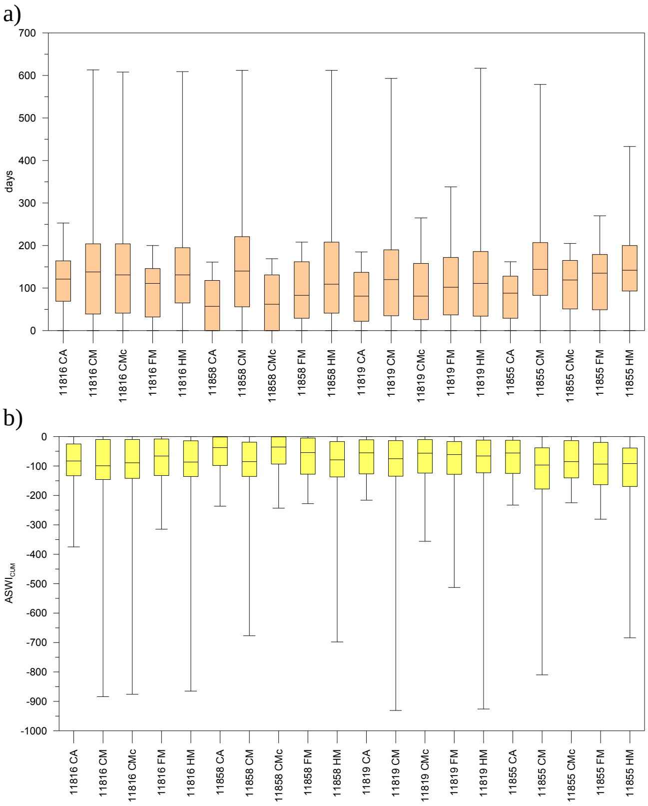

Fig. 2 Abnormal drought occurrence characteristics in periods of 1961-2013 (*ASWI*<0, *ASWC*< 50%, drought occurrence for >15 days); number of abnormally dry days (a), $ASWI_{CUM}$ (b)

From the results on abnormal drought occurrence and impact of soil and region (Fig. 2) we have found that yet ranging in narrow interval, performance of soils in different climate regions is different, thanks to differences in climate conditions, but also regional variations of important soil properties, namely soil texture propagated through available soil water capacity (Tab. 2).

Tab. 2 Available soil water capacity of soil types in the individual climate regions

Soil type	CA	CM	CMc	FM	HM
Clim. region	11819				
SWC [mm]	184	217	225	229	212
Clim. region	11816				
SWC [mm]	196	222	224	245	204
Clim. region	11855				
SWC [mm]	182	213	215	219	201
Clim. region	11858				
SWC [mm]	177	218	215	211	190

We also have not identified big differences among different climate regions in medians and variability, both for duration and severity of abnormal drought; with highest medians of drought duration for SW (Bratislava) and NE (Nitra) regions, highest variability of duration for SE (Hurbanovo) region. With closer look on individual soil types, we have found that CA is the best performing soil type in all regions with the lowest median and variability both for abnormal drought duration and its severity. With highest medians and variability both of abnormal drought duration and severity CM and HM (and also CMc in climate region 11816) are then the worst performing soils. Important feature which we have observed for CM and HM (and also CMc in climate region 11816) in some years is maximum length of abnormal drought duration for more than 365 days which indicates drought persistence throughout more than one years on these soil types.

Thanks to daily drought abnormality index (*ASWI*) we have calculated for each day of soil-water balance we were able to explore trends in abnormal drought occurrence in Danube lowland with different soil types (Tab 3). Soil type influences soil water balance mostly via available water capacity (Tab. 2), a potential amount of water soil can hold for longer time, which results in different lengths of abnormal drought periods with different soil types. We have observed increasing trend in length of abnormal drought duration in second period (1991-2012) which is obvious for all soil types with shift in severity of drought towards severe and extreme drought, yet drought duration increase is present throughout all drought severity classes (moderate, severe, and extreme drought). We have observed the lowest number of abnormally dry days with CA, likely due to groundwater table influence (groundwater table set to 150 cm in simulations). We have identified CM and HM as the worst performing soil types with highest number of abnormally dry days and days with moderate drought likely due to soil texture (high silt content, low clay content) and available water capacity values associated (Tab. 2).

Tab. 3 Average values of abnormally dry days weighted across soil types for periods of 1961-1991 and 1991-2012 (classification based on daily *ASWI* values according to T, only days with: *ASWI*<0, *ASWC*<50 %, drought occurrence for >15 days)

	1961-1990			
	days	Of this [days]		
		moderate	severe	extreme
CA	79	43	19	4
CM	139	65	26	8
CMc	97	49	19	4
FM	96	50	21	3
HM	134	64	25	8
	1991-2013			
	days	Of this [days]		
		moderate	severe	extreme
CA	92	56	35	8
CM	144	76	36	8
CMc	105	64	31	9
FM	106	62	32	10
HM	134	70	33	7

Taking three extremely dry years identified by Takáč (2013) we have tried to analyze spatial patterns of drought duration and severity as modified by soil type (Fig. 3). It is obvious that homogenous climate signal is significantly modified within the borders of individual climate regions by performance of soil types; which well corresponds to our findings from Tab. 3 with CA being the best and HM and CM the worst performing soil types. We can attribute slight regional differences also to different climate conditions which is obvious in different abnormal drought duration and severity spatial patterns developed during drought events with different characteristics (e.g. short period of extremely abnormal drought in 2012 compared to long and extremely abnormal drought in some regions in 1978 and 1990). Here, soil type itself via available water capacity (Tab. 2) can explain only part of observed spatial variability; groundwater table being likely other important parameter closely related to soil type which modifies resulting spatial pattern of abnormal drought duration and severity following the spatial distribution of main river channels.

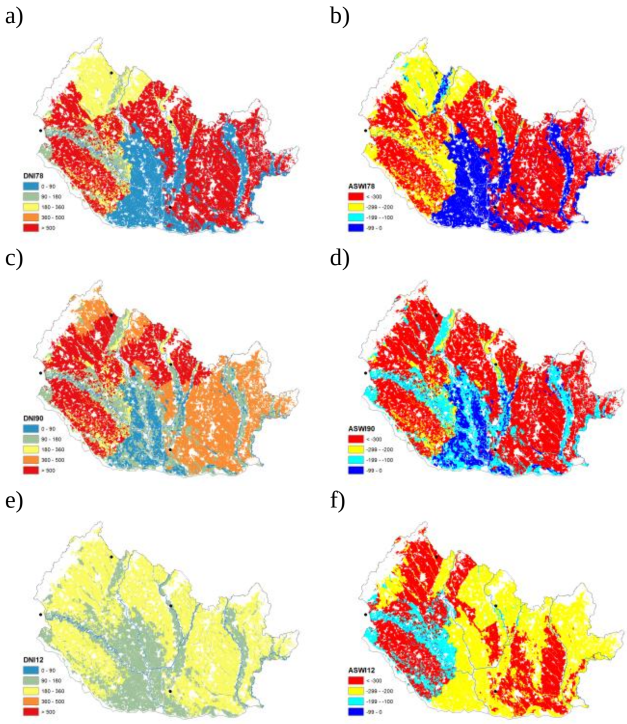

Fig. 3 Spatial patterns of drought abnormality for three extremely dry years (1978, 1990, 2012); number of dry days in 1978 (a), $ASWI_{CUM}$ in 1978 (b), number of dry days in 1990 (c), $ASWI_{CUM}$ in 1990 (d), number of dry days in 2012 (e), $ASWI_{CUM}$ in 2012 (f)

CONCLUSION

We have analyzed spatial patterns of abnormal drought occurrence (both duration and severity) in Danube lowland with spatial data on long-term (1961-2013) soil water balance calculated by Daisy model as influenced by soil types. We have found that yet ranging in narrow interval, performance of soils in different climate regions is different, thanks to differences in climate conditions, but also regional variations of important soil properties, namely soil texture propagated through available soil water capacity. We have observed increasing trend in length of abnormal drought duration in second period (1991-2012) of observed time interval and its severity which is obvious for all soil types. It is obvious that homogenous climate signal is significantly modified by performance of soil types also for abnormal drought events with different characteristics during extremely dry years 1978, 1990, and 2012. Considering abnormal drought occurrence, we have found *Mollic Chernozems* being the best and *Luvisols* and *Chernozems* the worst performing soil types in climate and natural conditions of Danube lowland.

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