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Drought Severity in Agricultural Land of Slovakia in the Years 2011-2013

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Abstract

Assessment of drought severity in agricultural regions of Slovakia in the years 2011-2013 is presented in the paper. Drought severity assessment is based on the soil water balance routine running on daily step. Standardized index based on daily available soil water content was used for drought severity classification. Criteria 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 continuous drought for fifteen or more days. Normal climate period 1961–1990 was chosen as reference period to enable historical comparison of drought severity and climate change impacts. Cumulative sum of available soil water index was used for drought quantification throughout its duration. Using the soil database allowed to analyse the spatial aspect of the drought severity. The results of the analysis confirmed the occurrence of meteorological drought in the years 2011 and 2012 and the occurrence of agronomic drought in the years 2011-2013. Greater areal extend of the impact of drought on crop production was observed only in the years 2012 and 2013.

Key words: Water balance, available soil water, soil texture, crop yield

Introduction

The growing and development of plants in conditions of Slovakia is largely determined by water regime. Soil water regime in Slovak lowlands depends mainly on atmospheric precipitation. Lack of soil water is a stress factor negatively affecting crop yields. Crop yields vary from year to year depending on the weather. On the one hand, crop production is adapted to long-term climate conditions, but on the other hand, frequent extreme weather conditions (droughts and heat waves) may be a limiting factor in agricultural production.

The drought differs in duration, severity and extent of the affected area. The term drought expresses a negative deviation from the normal water balance in a given area (Brázdil et al, 2009). Quantitative definition of the degree of abnormality of the drought through various climatic indices is difficult due to the interaction of meteorological, hydropedological, agronomical and the other factors. According to the meteorological dictionary (Sobíšek et al, 1993) we can distinguish meteorological drought, agronomic drought, hydrological drought and physiological drought.

In Europe, the increasing incidence of barren years is expected due to drought and heat waves, which will also have economic consequences (EEA, 2012). The territory of Slovakia in European context is not considered as an area prone to droughts. The risk of unfavourable dry years as a result of climate change will increase in Central Europe, which will result in an increased risk of soil erosion and lower productivity (Trnka et al, 2013). In hot and dry years, *Podunajská nížina* lowland, production potential will be increasingly limited by decreasing of water availability for crops and by heat waves (Eitzinger et al, 2012).

Spatial definition of drought and the likelihood of its occurrence is a prerequisite for the formulation of follow-up measures and activities related to building the necessary capacities and mitigation of its consequences.

Materials and methods

The crop growth is limited by sufficiency of soil water for evapotranspiration and therefore methods that include soil moisture are considered as the most suitable for evaluation of drought. The soil water dynamics is a result of flow of water in the system atmosphere - vegetation - soil - groundwater and it is one of the most dynamic soil properties. The time when meteorological drought (precipitation deficit) passes into agronomic drought (soil water deficit) depends on the water storage capacity of soils.

Soil water available for plants is considered to be the soil water in the interval between field capacity FC [mm] and wilting point WP [mm]. Soil water content below wilting point is not accessible for plants. Amount of soil water available for the plants is called available water capacity AWC [mm]. In agronomic practise soil water storage is usually expressed as available soil water content ASWC [mm]:

$$ASWC = SWC - WP$$

Soil water content SWC as well as FC and WP are calculated as weighted averages of horizons. Actual SWC_i in the day i can be calculated from the water balance equation:

$$SWC_i = SWC_{i-1} + P_i + CR_i - ET_i - RO_i$$

Where P_i is the precipitation, CR_i is capillary rise, ET_i is the evapotranspiration and RO_i is the runoff in the day i.

To evaluate anomalies in time series standardised indices are suitable. Standardised indices express relative relation of variable deviation from the average to standard deviation of time series. Standardisation allows achieve index distribution close to the Gaussian distribution (Takáč 2012). Standardization of the soil water allows to compare not only the intensity of droughts at different times, but also in different regions with different soil and climatic conditions. Proposed available soil water index $ASWI_i$ in the day i is calculated from available soil water content $ASWC_i$ in daily steps according to the equation:

$$ASWI_i = \frac{ASWC_i - ASWC_{AVE}}{ASWC_{SD}}$$

where $ASWC_{AVE}$ is long term average of *ASWC* and $ASWC_{SD}$ is standard deviation of *ASWC*. Similarly as in the case of climatic indices for $ASWC_{AVE}$ and $ASWC_{SD}$ calculation it is required 30 year duration of the time series. Normal climate period 1961–1990 was chosen as reference period to enable historical comparison of drought severity as well as climate change impacts.

In accordance with assessment established in climatology (Lapin *et al*. 1988) boundaries of 25 % exceeding probability for moderate drought, 10 % exceeding probability for severe drought and 2 % exceeding probability for extreme drought have been set (Takáč, 2012).

Drought is related to the long term mean conditions and it is defined as long term occurrence of *SWC* below average value. Basic assumptions for drought are 1) the SWC is below 50 % of AWC and 2) SWC is below long term average SWC at the same time. Drought duration was defined as consecutive days of negative *ASWI*. Exceeding probability intervals of *ASWI* were used for drought severity classification (Table 1). The beginning of a drought period of a given degree is determined by the day when *ASWI* falls below threshold value and the drought continues until the threshold is exceeded again. In order to classify the drought in a particular degree the duration must be continuous for at least 15 days. In the case that two dry periods are interrupted by a short wetter period, this interruption is ignored under condition that it lasts for less than 10 % of the length of the two dry periods. (Takáč, 2013a). Cumulative sum of *ASWI* was used for the drought quantification throughout its duration:

$$ASWI_{CUM} = \sum_{i=1}^{N} ASWI_i$$

where *i* is the number of the day and N is the number of the days in the period with negative *ASWI*. Based on the probability of occurrence in the reference period 1961-1990 the rounded values of $ASWI_{CUM}$ were chosen for dry period classification (Table 2).

1x1 km (soil) and 10x10 km (climate) spatial resolution data served the input for the soil moisture balance routine running on daily step. Daily climate data (1961

– 2013) on minimum, maximum and average air temperature (°C), sunshine duration (hour), vapour pressure (hPa), average wind speed ($m.s^{-1}$) and rainfall (mm) from totally 71 climate stations distributed regularly across agricultural land of Slovakia was provided by Slovak Hydrometeorological Institute. Data was interpolated to 10x10 km grid locations by algorithm developed by JRC (Crop Growth Monitoring System – CGMS) and further modified for national needs by Novakova (2007). Reference crop evapotranspiration and actual evapotranspiration was calculated for each cell afterwards using Penman-Monteith equation (Allen et al, 1998) implemented within the CGMS system. Land evaluation maps in 1:5000 scales (Linkeš et al 1996) provided information on agricultural soil texture class distribution. Spatially dominant topsoil texture class from the map was then assigned to each relevant 1x1 km cell location and taken as representative value for the whole 120 cm deep soil profile. National soil profile database (AISOP, Linkeš et al. 1988) counting 17 740 soil profile records provided data on soil analytical properties. Soil texture class representative sand, silt and clay content was calculated as an average from the AISOP data and all other necessary hydro-physical parameters (soil bulk density, soil water content at field water capacity and wilting point) were then estimated by HYPRES pedotransfer functions (Wosten et al. 1998, 1999). Available water capacity (AWC) for the soil profile was calculated as follows:

AWC = (FC-WP)*h,

where AWC is available water capacity (mm), FC is water content at field water capacity (cm^3/cm^3), WP water content at field wilting point (cm^3/cm^3), and h is soil depth (mm) which is 120 cm in our case. Representative soil profile values used for pre-defined soil texture classes are listed in Table 3.

The 120 cm soil profile value of AWC was then modified for each 1x1 km grid cell based on information on dominant soil depth and stone content coming from Land evaluation maps (Linkeš et al 1996). If soil depth was less than 60 cm or stone content in top 60 cm of soil was more than 50% the AWC value was decreased of 25%. If soil depth was less than 60 cm and stone content in top 60 cm was more than 50%, the AWC value was decreased of 50%. Un-modified AWC value was left in all other cases. Groundwater influence was assumed for all locations (1x1 km grid cells) with dominant Gleysols, Histosols or Gleyic Fluvisols having also heavy texture. Groundwater influence as estimated based on soil information well corresponds with spatial distribution of the lowest parts of the big alluvial areas of the *Podunajská nížina* lowland. Spatial intersection of climate and soil grid data yielded totally 3.865 simulation units (SimU) which represent spatial units homogenous as for its climate and soil (AWC, groundwater influence). Each SimU is a spatial zone consisting of 1 – 100 1x1 km grid cells located within the borders of only one particular 10x10 km climate cell.

Seven strategically important crops were selected for evaluation of crop yields, treated separately in two groups as:

1) winter and spring crops (winter wheat, spring barley, winter rapeseed) and

2) summer crops (corn maize, sunflower, sugar beet, and potato).

Long-term average yields of all crops (1997 – 2010) were calculated from NUTS3 level statistical data provided by the Statistical Office of the Slovak Republic. Yields for 2011-2013 were then compared to long-term averages using relative deviation as the statistical measure of observed differences:

$$RD_i = 100 * \frac{(Y_i - Y_{avg})}{Y_{avg}}$$

Where RD_i is relative deviation (%), Y_i is respective yield (t/ha) in the considered year, and Y_{avg} is long-term average yield.

Results

Yield variability is significantly affected by soil water dynamics during growing period as well as during non-growing period. Consequence is given to the winter water supply. It is optimal if sufficient snow cover was formed during the winter and snow melts slowly in early spring. In general, the soil moisture has an annual cycle. Maximum soil water storage is at the end of the winter and minimum occurs in the summer months. SWC almost every year during the summer months falls below 50% of AWC in the southern regions of Slovakia.

This is a normal recurring phenomenon. Crop production is adapted by the structure of crops and their varieties or supplementary irrigation.

Duration of the period with SWC below 50 % of AWC is different in the individual regions and it varies from year to year. Such period occurs in the west Slovakian lowlands almost every year. Continuous period with SWC below 50 % of AWC lasts from 50 days to 100 days in average on *Podunajská nížina* lowland as well as in the southern part of *Záhorská nížina* lowland. Locally, especially on light sandy soils, it is more than 100 days in average. On the contrary, duration of the period with SWC below 50 % of AWC is in average less than 50 days in the most of the country territory (Fig 1).

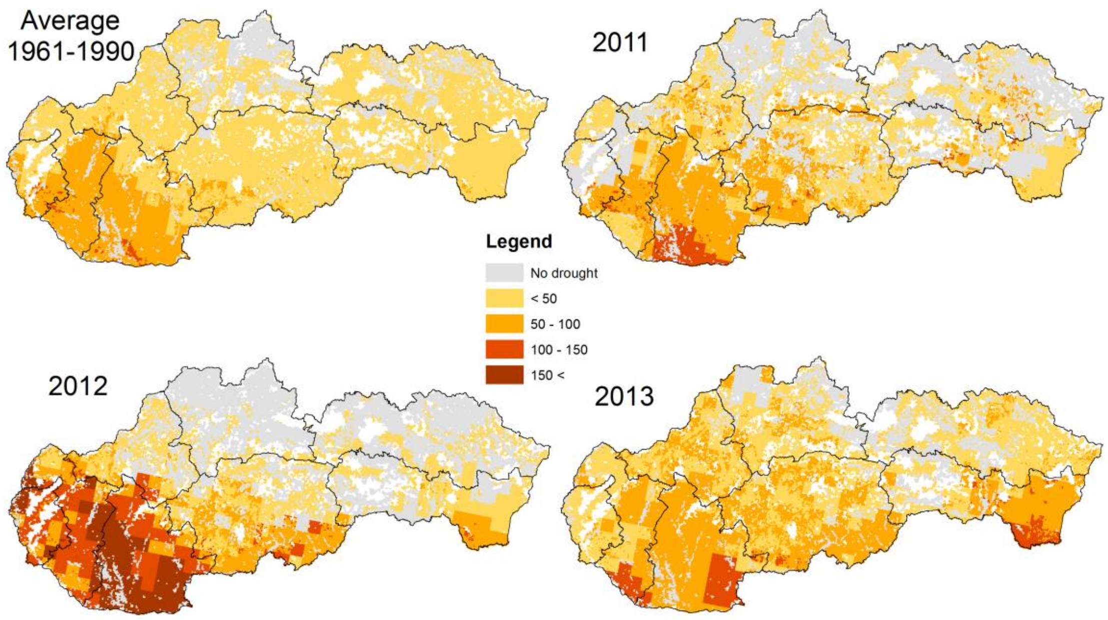

Fig 1 Number of days with SWC below 50 % of AWC in the period 1961-1990 and in the years 2011, 2012 and 2013

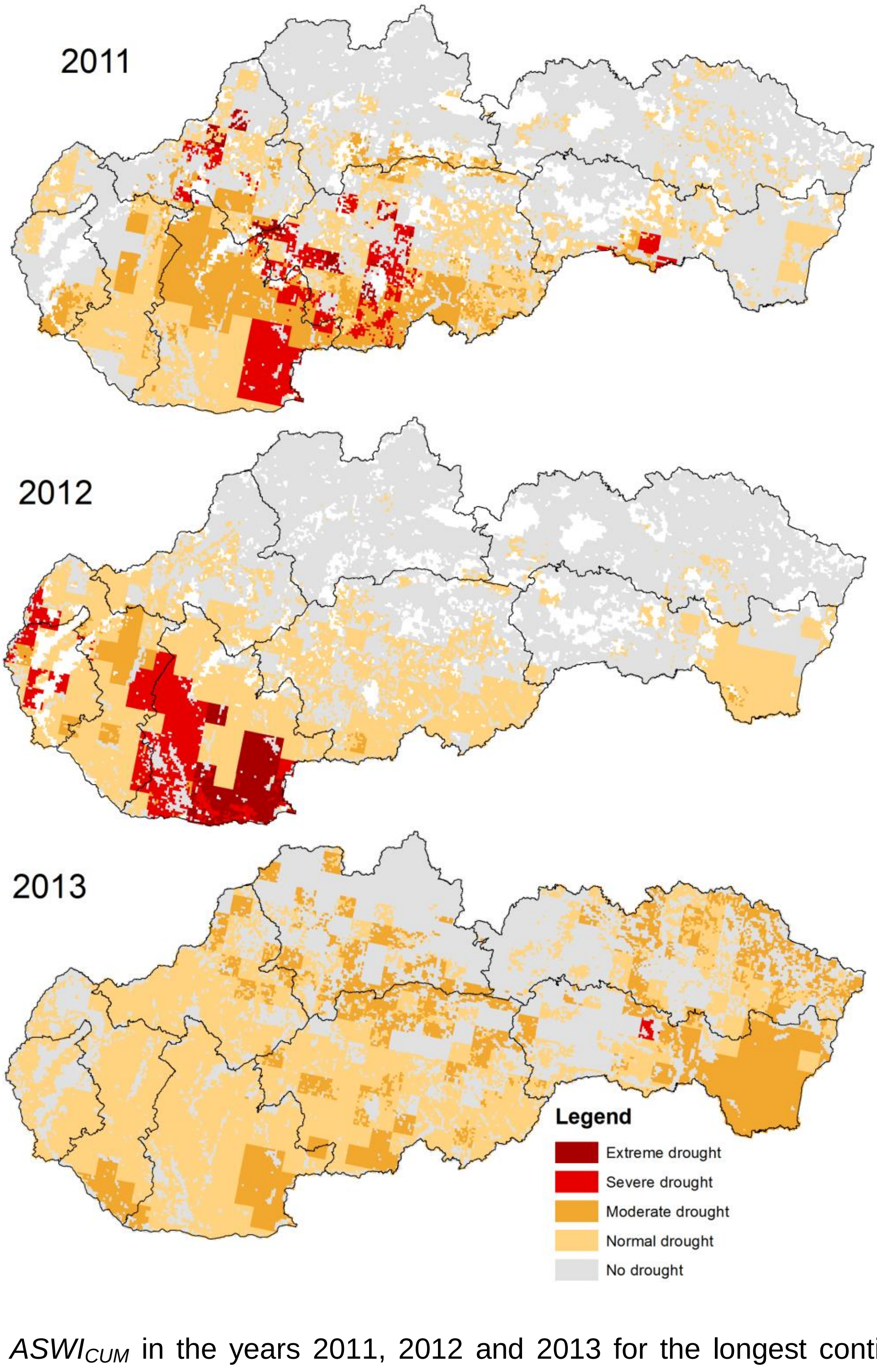

Fig 2 *$ASWI_{CUM}$* in the years 2011, 2012 and 2013 for the longest continuous drought period

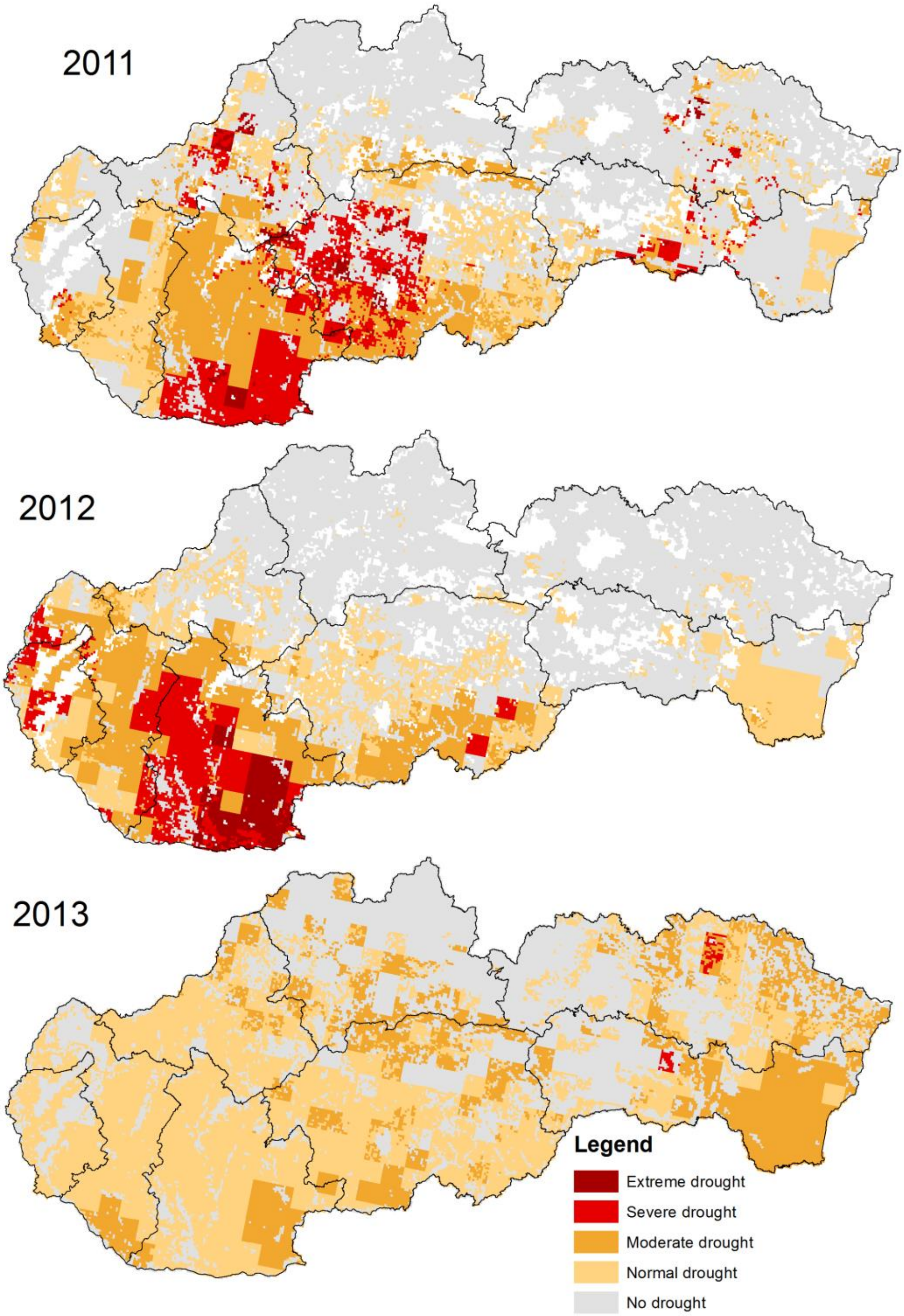

Fig 3 *$ASWI_{CUM}$* in the years 2011, 2012 and 2013 for the entire year

In 2011, the dry period lasted more than 100 days in the southeast part of the *Podunajská nížina* lowland and in 2012 in the whole south-western Slovakia, while in the central and eastern part of the *Podunajská nížina* lowland as well as on *Záhorská nížina* lowland it was more than 150 days. In 2013, the dry period lasted more than 100 days in the southeast of the *Podunajská nížina* lowland, in lower part of *Žitný ostrov* and in the southern part of *Východoslovenská nížina* lowland (Fig 1).

From the statistical point of view the year 2012 was similar to the year 2011 according to available soil water content anomalies. Drought occurred on 45 per cent and 44 per cent of the area in the years 2011 and 2012, respectively. The areal average of $ASWI_{CUM}$ was -138 and -137 and the areal standard deviation of $ASWI_{CUM}$ was 88 and 90 in the years 2011 and 2012, respectively. Severe drought occurred on the 9 per cent and 8 per cent and extreme drought occurred on 1 per cent and 3 per cent of the area in the years 2011 and 2012, respectively (Fig 4).

According to the $ASWI_{CUM}$ continuous severe drought occurred on the southeast of *Podunajská nížina* lowland, central part of *Váh* valley and in the western part of *Banská Bystrica* region while locally reached the extreme severity in the year 2011 (Fig 2). Several short periods of normal or moderate drought appeared also in the east Slovakia. The total sum of these shorter periods reached threshold of severe drought in some locations (Fig 3).

In the year 2012, severe drought occurred in the eastern part of *Podunajská nížina* lowland and in the part of *Záhorská nížina* lowland. Extreme drought was in 2012 in the southeast of *Podunajská nížina* lowland. In the year 2013, severe drought appeared only locally in the east Slovakia (Fig 2).

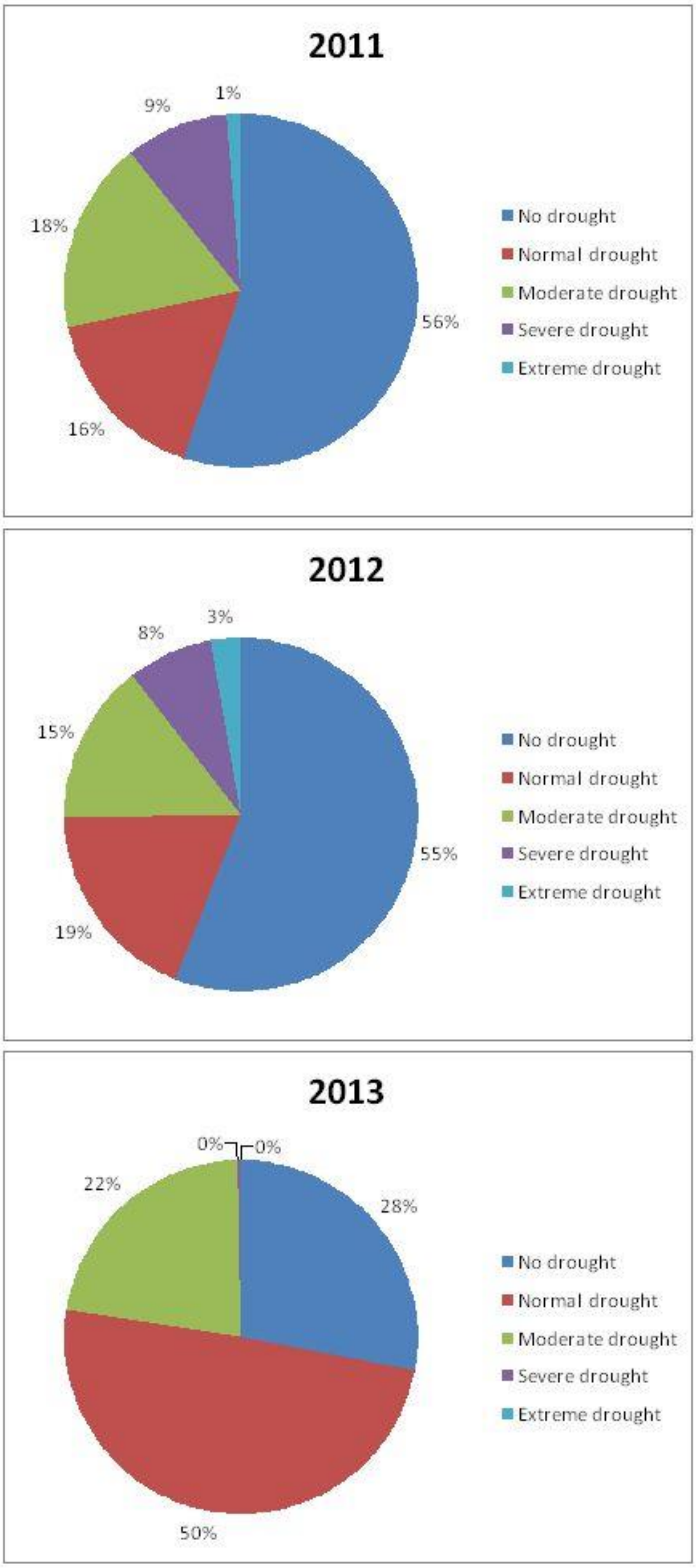

Fig 4 Statistical distribution of drought degree in the years 2011, 2012 and 2013

Discussion

According to the precipitation percent of normal the year 2011 was driest from the years in question. Year 2012 was dry in the most of territory. The year 2013 was normal or wet (Faško et al, 2014).

According to SPI the year 2011 was drier than the year 2012 (Takáč, 2013b). Annual SPI average from 33 meteorological stations was -0.90 in the year 2011 while in the year 2012 it was -0.36. Extreme drought occurred in the southern part of *Podunajská nížina* lowland, southwest part of *Košická kotlina* basin and central part of *Váh* valley in the year 2011. Moderate drought according to the annual SPI was in northern part of *Podunajská nížina* lowland and some submountain regions in the year 2011. On the other hand, according to the annual SPI only moderate drought occurred in the western part of *Záhorská nížina* lowland, central part of *Podunajská nížina* lowland and in *Rimavská kotlina* basin in the year 2012. On the contrary, the year 2013 was normal or wet according to the precipitation totals. Despite this fact, normal or moderate drought occurred on the 72 per cent of the area of agricultural land according to $ASWI_{CUM}$. This was caused by increased demand for the evapotranspiration due to high temperatures.

Dry years are usually characterised by decreases in crop yields. Compared to long-term average yield, normal yield of winter and spring crops (winter wheat, spring barley) were observed for most regions of the Slovakia in 2011, slightly higher yields were observed mostly in northern regions of Slovakia. Different situation was recorded in 2012 when in western parts of Slovakia the yields were lower than long-term average, whereas in eastern regions yields attained were normal or higher then long-term average. In the year 2013, below average spring barley yields were observed especially in the southern districts while the winter wheat yields were mostly above average (Fig 5).

Higher yields than long-term average were observed for summer crops in most regions of Slovakia in 2011. In 2012 the spatial pattern of relative deviations for summer crops followed the pattern of winter and spring crops; i.e. lower yields than long term average in western regions and higher in eastern regions.

Similar pattern was observed also for the summer crops in the year 2013 (Fig 6).

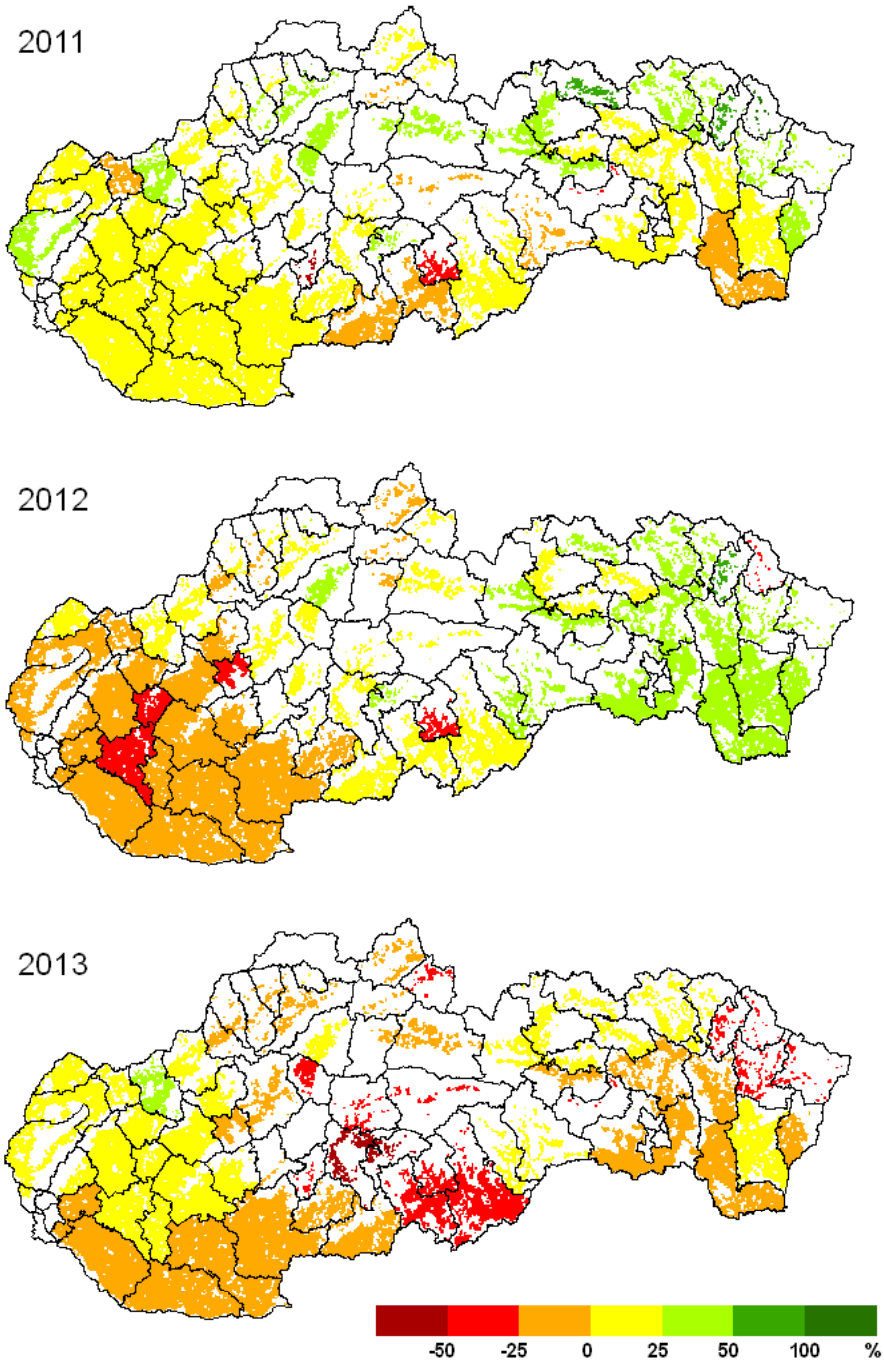

Fig. 5 Relative deviation (%) of spring barley yield in 2011-2013 from long-term average yield for 1997 – 2010

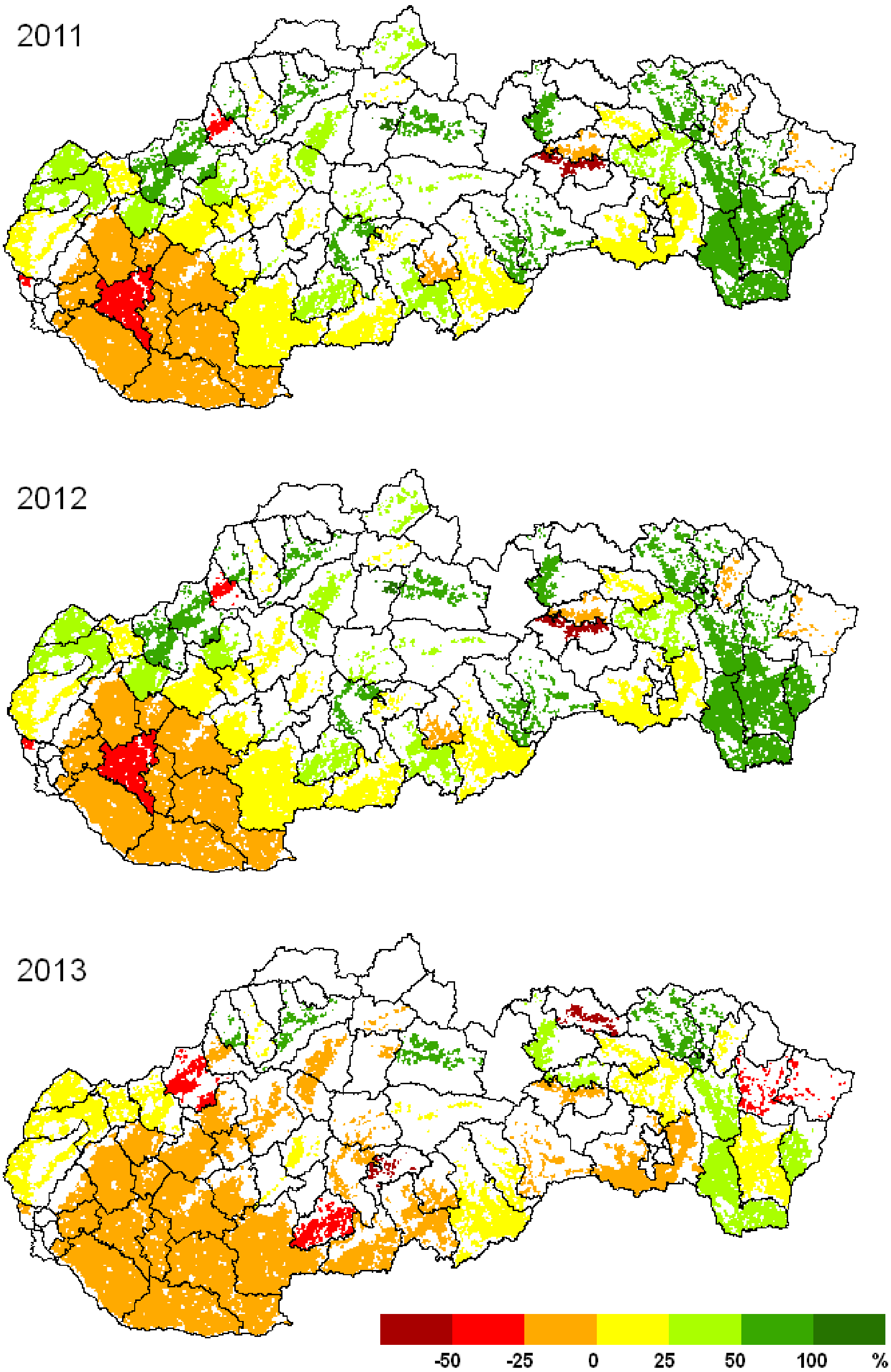

Fig. 6 Relative deviation (%) of maize yield in 2011-2013 from long-term average yield for 1997 – 2010

Regarding to the drought impacts on crop yields it is important in which part of growing season the drought occurs. In the year 2011, the severe drought started in August and lasted till December while in the year 2012 the severe drought occurred in the spring and lasted till July. In the year 2013, the drought in the southern regions lasted from June to September.

Conclusion

The results of the analysis confirmed the occurrence of meteorological drought in the years 2011 and 2012 and the occurrence of agronomic drought in the years 2011-2013. Regarding to the drought impacts on crop yields the distribution of the precipitation during the growing season and hence the period of drought occurrence plays an important role.

Standardised available soil water anomaly index gives information on drought severity for the particular day. It can be employed in real-time assessment of actual drought situation development as a part of early-warning system and also for taking the decisions on drought mitigation at local level directly by individual soil users. Cumulative value of the standardised available soil water anomaly index gives an opportunity to quantify and classify even the extremely long drought event during the whole period of its impact. Introduction of the reference period can moreover help to describe the drought severity within the particular region in historical context and as such, on higher decision-making levels to support decisions on compensation payments for farmers or for to plan long-term mitigation measures. Climate data, soil data and GIS coupling gives an opportunity for building-up the National drought information system based on this methodology.

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Summary

Rastlinná produkcia je v podmienkach Slovenska vo veľkej miere determinovaná vodným režimom pôdy. V príspevku prezentujeme hodnotenie sucha na Slovensku v rokoch 2011-2013 z hľadiska jeho závažnosti. Pre výpočet zásoby vody v pôde sme použili zjednodušenú rovnicu vodnej bilancie, ktorá berie do úvahy údaje o počasí aj o pôde. Pre klasifikáciu závažnosti sucha bol použitý štandardizovaný index využiteľnej dennej zásoby vody v pôde. Kritériami pre posudzovanie výskytu sucha boli zásoba využiteľnej vody v pôde menšia ako 50% využiteľnej vodnej kapacity, podpriemerná zásoba vody v pôde v porovnaní s dlhodobým priemerom a súvislé trvanie obdobia 15 a viac dní. Normálové klimatické obdobie 1961-1990 bolo vybrané ako referenčné obdobie na historické porovnávanie závažnosti sucha a dôsledkov zmeny klímy. Kumulatívna hodnota indexu bola použitá na kvantifikáciu sucha počas celej doby jeho trvania. Využitie pôdnej databázy umožnilo analyzovať sucho aj z priestorového hľadiska. Výsledky analýz potvrdili výskyt meteorologického sucha v rokoch 2011 a 2012 a výskyt agronomického sucha vo všetkých hodnotených rokoch. Väčší územný rozsah dopadov sucha na úrody poľných plodín bol pozorovaný len v rokoch 2012 a 2013.

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Table 1 Degrees of drought severity based on the available soil water index *ASWI* (Takáč, 2013a, 2013b)

Drought degree	Extreme drought	Severe drought	Moderate drought	Normal drought
Probability interval [%]	≤ 2%	2.1% to 10%	10.1% to 25%	25.1% to 50%
ASWI interval [–]	≤ –1.8	–1.8 to –1.151	–1.15 to –0.721	-0.72 to 0

Table 2 Degrees of drought severity based on the cumulative available soil water index $ASWI_{CUM}$ (Takáč, 2013b)

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

Table 3 Soil texture class specific average sand, silt, and clay content, estimated soil hydro-physical properties and available soil water capacity in 120 cm soil profile.

Texture class	clay	silt	sand	Bulk density	Field capacity	Wilting point	AWC
	%			g/cm^3	%		mm
Sand and loamy sand	7.7	22.3	70.0	1.6	21.69	4.19	210
Sandy loam	13.0	41.3	45.7	1.45	29.28	7.60	260
Loam	20.9	53.3	25.8	1.4	34.18	11.95	266
Clay loam	31.4	52.4	16.2	1.35	37.87	16.81	252
Clay	44.3	46.4	9.4	1.3	41.91	21.54	244