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Establishment of agricultural drought monitoring at different spatial scales in southeastern Europe

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ABSTRACT

To detect temporal and spatial variability of drought is one of the most challenging issues of drought monitoring in the specific country or region due to the fact that there is no standard definition of severity and duration of different types of drought. Crop water deficit (CWD) simulated by crop water balance model IRRFIB supplemented with some *in-situ* soil water measurements by Time-Domain Reflectometry (TDR) measurement technique are proposed as tools for local agricultural drought monitoring in this study. Moving to regional drought monitoring the main constraint represents data availability of different sources. Available global data sets are of assistance for preparing regional drought monitoring products. In the study two specific products designed for regional scale are described: preliminary maps of the SPI (Standardized Precipitation Index) and products generated by implementation of numerical weather prediction model. It seems to be a lot of potential in both products for a first overview of key meteorological parameters in the region.
The development of drought in the year 2009 was under examination and also yearly results for different periods after 1971. Dry periods in the year 2009 heavily impacted cereals in Slovenia. Maize yield showed best agreement with crop water deficit (r = 0.65) and SPI on the time scale of six months for September (r = 0.61). SPI was not suitable for describing agricultural drought in the periods with higher evapotranspiration rate. For more agricultural oriented drought monitoring more indices should be included into the consideration.

Key words: drought monitoring, agriculture, IRRFIB, SPI, numerical modelling, crop water balance

IZVLEČEK

VZPOSTAVLJANJE MONITORINGA KMETIJSKE SUŠE V JUGOVZHODNI EVROPI NA RAZLIČNIH PROSTORSKIH SKALAH

Eden izmed večjih izzivov na področju monitoringa suše v določeni državi ali regiji je določanje časovne in prostorske variabilnosti suše, saj ne obstaja splošna definicija, ki bi določala intenzivnost in trajanje različnih tipov suše. V študiji predlagamo primanjkljaj vode pri rastlinah (CWD), simuliran z vodnobilančnim modelom IRRFIB in podprt z *in-situ* meritvami vode v tleh s TDR tehnologijo, kot primerno orodje za lokalno določanje kmetijske suše. Na širšem, regionalnem nivoju pa se pojavi ovira pri dostopnosti podatkov, zato si pri pripravi regionalnih produktov lahko pomagamo z globalnimi nizi. Opisujemo dve možnosti, primerni za regionalno skalo: preliminarne karte standardiziranega padavinskega indeksa (SPI) in produkte, ki jih generiramo z implementacijo numeričnega modela za napovedovanje vremena. Pri obeh se kaže velik potencial za prvi, splošni pregled nad stanjem glavnih meteoroloških parametrov v regiji. Za primer smo vzeli razvoj suše leta 2009 ter letne rezultate za različna obdobja po letu 1971. Leta 2009 so sušna obdobja hudo prizadela poljščine v Sloveniji. Pridelek koruze kaže najboljšo povezanost s primanjkljajem vode CWD (r = 0,65) in z indeksom SPI na šestmesečni časovni skali za september (r = 0,61). Indeks SPI se ni izkazal za primernega pri obravnavi obdobij z višjo stopnjo potencialne evapotranspiracije. Opozarjamo še na dejstvo, da bi bilo potrebno za bolj kmetijsko usmerjen monitoring suše vključiti več različnih indeksov.

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Ključne besede: monitoring suše, kmetijstvo, IRRFIB, SPI, numerično modeliranje, vodna bilanca rastlin

1 INTRODUCTION

All types of drought originate from a deficiency of precipitation (Wilhite and Glantz, 1985). Meteorological drought is defined as extended period of time with significant precipitation deficit. Agricultural drought is defined more commonly by the availability of soil water to support crop and forage growth than by departure of normal precipitation over some specific period of time (Wilhite, 2007). It can also be determined by a period of reduced plant growth with a prolonged and abnormal soil water deficiency. Many attempts were made to create agricultural drought index, some of the 'rainfall indices' can be related, for example, to soil and crop type, crop status and climatological parameters such as air temperatures, air humidity and wind (Maracchi, 2002). A soil water deficit within the rooting zone can result in crop water stress, depending on the crop status and climatological factors affecting evapotranspiration.

Drought indicators and triggers are important for several reasons: to detect and monitor drought conditions; to determine the timing and level of drought responses; and to characterize and compare drought events.

However, agricultural drought depends on soil moisture and evapotranspiration deficits. For this reason, water balance model IRRFIB was developed, which computes the main components of water balance aiming to quantify drought stress of crop canopy. On a daily basis it evaluates soil moisture content. It also computes seasonal and annual integrated drought stress by the ratio of actual to potential transpiration.

A simulation study of the soil moisture content under a maize field was carried out. The approach of analysing the effect of drought on crop using dynamic crop models has the advantage to include all relevant drought impact factors of the soil-crop-atmosphere system over short time periods. This is of special interest when answering the questions whether agrometeorological model IRRFIB is sufficient to simulate the water balance and the occurrence of drought on local scale.

Beside assessment of drought conditions on local scale (which can be extremely variable due to local conditions) there is a need to estimate situation on larger scale. One of possible (and frequently applied) procedures is application of point measurements and geostatistical techniques for spatial interpolation (such as kriging; see for example Pardo-Iguzquiza, 1998). There are other possibilities; numerical weather prediction (NWP) models (that are routinely used for weather forecast) are potentially useful tool for drought monitoring. Under term NWP model we usually understand mathematical set of equations describing motion of air and other events that take place in the atmosphere. Modern NWP models are constructed around the full set of primitive equations which govern atmospheric motions and are formulated in discrete numerical form; some processes are not fully resolved and are rather presented by parameterization, such as turbulent diffusion, radiation, moist processes, heat exchange, soil, vegetation, surface water, convection etc. NWP models simulate values in regular grid mesh; error is expected to be spread over whole computing domain and doesn't strongly depend on distance from nearest observation as in the case of statistical interpolation. For larger areas with various density of observation NWP models seem to be useful tool for drought detection despite their known deficiencies (see for example Ebert and McBride, 2000).

2 MATERIALS AND METHODS

2.1 Site descriptions

The experimental fields were located in the southeastern Slovenia. Murska Sobota is located on flat area, at 46° 39' latitude, 16° 11' longitude, and at an elevation 188 m a.s.l. Platform for meteorological measurements is located within agricultural research area. Meteorological observations were recorded in the frame of national meteorological network. Climate is characterized by cool, wet winter and warm, dry summers, with an average (1971-2000) annual precipitation of 805 mm (Figure 1).

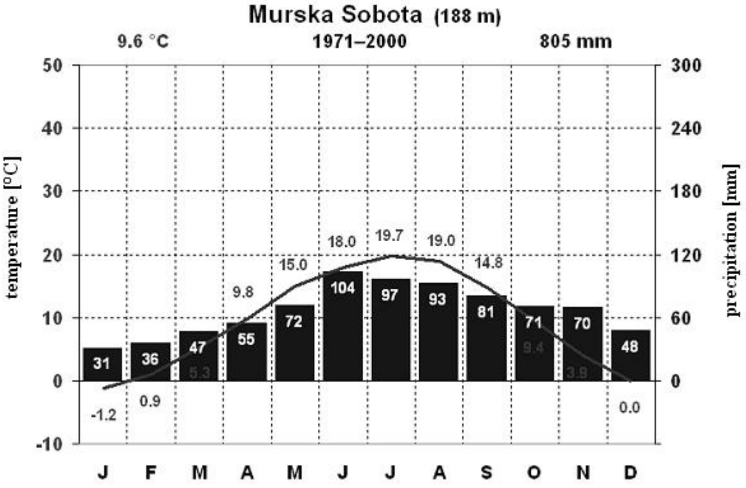

Figure 1: Climate diagram for Murska Sobota (source: EARS, 2009)

Slika 1: Klimagram za Mursko Soboto (vir: ARSO, 2009)

Around 60 % of the precipitation occurs between April and September. Mean annual air temperature is 10.2 °C, with the mean monthly maximum of 37.8 °C occurring in August. Precipitation during the recent vegetation periods was less than 60 % of the long-term average, primarily due to seasonal shift to more dry vegetation periods. Average annual potential evapotranspiration is around 700 mm, around 80 % occurring during the vegetation period.

2.2 Climate data

The following meteorological parameters were used in the study: minimum air temperature, maximum air temperature, relative air humidity, cloudiness or duration of irradiation, wind speed and precipitation. Daily meteorological data for the period 1971-2009 were obtained from the database of the Slovenian Meteorological Office (EARS, 2009).

2.3 Crop data

Phenological data for grass (*Dactylis glomerata)* and maize (*Zea mays*) have been obtained from the database of the Slovenian Meteorological Office (EARS, 2009). The phenological stages used in the study included sowing, emergence, 3rd leaf, beginning of male flowering, beginning of female flowering, milky ripe, vax ripe, full ripe and harvest of maize (middle ripening class) for the period 1971-2009 with some missing years in the dataset. For model IRRFIB verification with regard to soil moisture measurements phenological data of grass heading and flowering for the period 2006-2008 were used. For the period 1993-2008 maize yield data were obtained from Agriculture Institute of Slovenia. Over time some cultivars were changed but still remain in the same FAO ripening class.

2.4 Drought impact reports

The drought impacts on crops were obtained from Agrometeorological reports of Meteorological Office of the Republic of Slovenia as timely information on the severity and spatial extent of drought and its associated impacts (EARS, 2009a). Improved information on drought impacts helped to identify the type of impacts and where they were occurring.

2.5 Soil data

Soil water characteristics and hydraulic conductivity functions have been described through field capacity (Fc) and wilting point (Wp) through experimental data. Soil water holding capacity (SWC) is around 100 mm. For soil water measurement Time-Domain Reflectometry (TDR) technology was used; probes are mounted in 10, 20 and 30 cm depths at both meteorological stations. TDR device (*Trime*) for continuous and non-destructive determination of volumetric soil moisture consists of electronic sensor which measures dielectric constant of the material and recalculates it to the soil moisture content. Data are available in 10 minute intervals. For the model verification measurements for the period 2006-2008 were obtained. The experimental plots with yield data are near the meteorological station in Murska Sobota, where the soils have the same characteristics.

2.6 Model IRRFIB description

IRRFIB simulates the water balance in the crop-soil-system on the daily basis. The model calculates evapotranspiration (ET) using the Penman-Monteith equation (FAO, 1998) for different crop covers considering the relevant processes of heat, water and vapour transport in the soil-crop-atmosphere interface (Table 1). Crop coefficients and rooting depths are linearly interpolated during each phenological phase and are used for calculating actual evapotranspiration and soil water reservoir, respectively.

Table 1: Input and output parameters of IRRFIB model (Sušnik, 2006).

Tabela 1: Vhodni in izhodni parametri modela IRRFIB (Sušnik, 2006).

	INPUT	**Value**	**OUTPUT**
Weather	Minimal air temperature	Daily values	Potential evapotranspiration
	Maximal air temperature	Daily values	Actual evapotranspiration
	Relative air humidity	Daily values	
	Cloudiness / Duration of irradiation	Daily values	
	Wind speed	Daily values	
	Precipitation	Daily values	
Crop	Phenological phase	Dates for maize, grass	Crop coefficient (daily)
	Crop coefficient (for phase)	0-1 (grass); 0-1.1(maize)	Crop water demand
	Roots depth	20 cm (grass); 0-50 cm (maize)	Irrigation demand
Soil	Field capacity	Different values for locations	Precipitation infiltration
	Wilting point	Different values for locations	Soil water content
			Soil water deficit

Crop water simulation model IRRFIB was tested for a variety of crops and applications (Sušnik et al, 2006). Model results were validated against water content measurements using a TDR sensor in 2004 at the measurement site of meteorological station in Ljubljana. Strong correlations were obtained during the testing period (r^2 = 0.94) (Sušnik, 2006). Model performance was also tested for a test site in Braunschweig Germany (Sušnik, 2005). Recent study with model SIMPLE showed good degree of concomitance with IRRFIB model (r^2 =0.69).

Model runs were performed for the period 1971-2008 due to availability of phenological data.

Water balance (B) and crop water deficit (CWD)

Water balance of the first day assumes that water reservoir is full as follows:

$$B_1 = PK \cdot Z$$

PK	vol. % of water at PK
Z	rooting depth [mm]

For the crop coefficient K_c and rooting depth Z linear approximations in the vegetation period were performed. The volume of plant available water (PAW) is defined as ($1 - pp$) . In this study pp equals 0.5. The lower threshold of available water is defined as $B_{threshold}$:

$$B_{threshold} = \left(TV + (PK - TV)\,pp\right) \cdot Z \qquad \ldots (2)$$

Following data are needed for the water balance calculation for i-th day: reference evapotranspiration ET_{oi} , daily precipitation P_i , crop coefficient K_{ci} , rooting depth Z_i and water balance on previous day B_{i-1} .

Daily water deficit on day i CWD_i is a difference between daily precipitation and crop evapotranspiration (ET_{ri}), which can be expressed as:

$$ET_{ri} = K_{ci} \cdot ET_{oi} \qquad \ldots (3)$$

$$CWD_i = P_i - ET_{ri}\text{, if } B_{i-1} > B_{threshold} \qquad \ldots (4)$$

$$CWD_i = P_i - ET_{ri}/2\text{, if } B_{i-1} \leq B_{threshold} \qquad \ldots (5)$$

In our study only daily water deficits with values less than $B_{threshold}$ were used.

The water balance on day i, is defined as

$$B_i = B_{i-1} + CWD_i$$

if $B_i < TV_i \cdot Z_i$ is equal to $TV_i \cdot Z_i$ … (6)

if $B_i \overset{(1)}{>} PK_i \cdot Z_i$ is equal to $PK_i \cdot Z_i$ … (7)

Number of days with CWD was summarized over vegetation period.

2.7 Drought stress days (DS)

Drought stress occurs in situations where crop evapotranspiration (ET_r) is less than potential evapotranspiration (ET_o). Inside IRRFIB model drought stress is simulated as impact of soil water availability on ET_r , assuming that soil moisture limited ET_r beyond a threshold suction value (50 % of Fc) and than decreased linearly to zero at permanent wilting point. The limit of crop available soil water is a threshold, under which a half of actual evapotranspiration is subtracted from precipitation amount, resulting in daily water deficit. During vegetation period drought stress intervals were analysed. Days with the soil water content under this limit are considered as days with drought stress.

2.8 Standardized precipitation index (SPI)

Standardized Precipitation Index represents the transformation of the precipitation time series into standardised normal distribution. Detailed description of transformation procedure can be found in Guttman (1999). Due to simplicity (it requires only precipitation data) it became one of most frequently applied tools for drought monitoring. Variable time scale of SPI calculation enables description of drought conditions in meteorological, agricultural and hydrological applications. Drought dynamics is another important feature that is addressed with variable time scale; it is capable of determining the onset, duration and intensity of drought. We have implemented a modified version of SPI software from Colorado Climate Center, which is capable of calculating SPI on specified time scale and also accounts for zero precipitation. Time scale was specified as the number of days or months provided daily or monthly precipitation sums at meteorological stations as input data.

2.9 Statistical methods

Statistical measures like average error (AE), root mean square error (RMSE), modelling efficiency (EF), coefficient of residual mass (CRM) and Pearson's correlation coefficient (r) are used in the study. For the classification of vegetation periods regarding drought severity, Conrad-Chapman percentile classification (Sušnik, 2005) is used.

3 RESULTS

3.1 Model IRRFIB verification

Comparison of modelled grass water balance with measurements was made for three years (2006-2008) in Murska Sobota. Values of AE, RMSE and CRM are indicating little deviation between measured and simulated values when they are near zero. On the other hand, the optimum value for EF is 1, representing a good modelling efficiency (Elmaloglou and Malamos, 2000). CRM is negative, where IRRFIB obviously overestimates soil water content. Correlation r with measurements is significant (Table 2).

Relatively small overall differences imply that IRRFIB can be a useful tool in simulating soil water balance (Figure 2).

Table 2: Five statistical criteria for comparison of measured (Trime) and simulated (IRRFIB) values of soil water content in Murska Sobota

Tabela 2: Pet statističnih kriterijev za primerjavo izmerjenih (Trime) in simuliranih (IRRFIB) vrednosti količine vode v tleh v Murski Soboti

location	AE [vol.%]	RMSE [%]	EF	CRM	r
Murska Sobota	2,11	20,40	0,55	-0,10	0,84**

** Correlation is significant at 0.01 level.

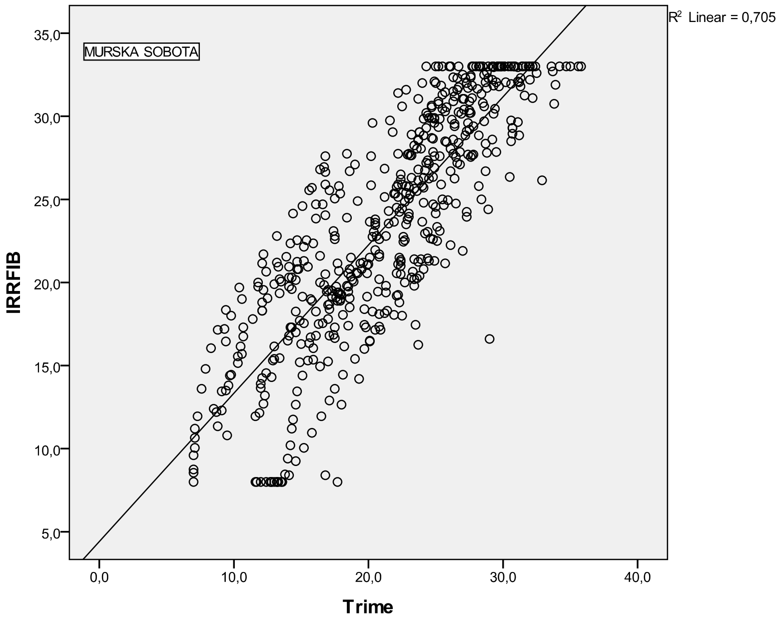

Figure 2: Comparison of measured (Trime) and simulated (IRRFIB) values of soil water content in Murska Sobota in the period 2006-2008

Slika 2: Primerjava izmerjenih (Trime) in simuliranih (IRRFIB) vrednosti količine vode v tleh v Murski Soboti v obdobju 2006-2008

3.2 Comparison of SPI with water balance

The case study for year 2009 revealed the importance of relationship between drought duration and water balance during the growing season, when monitoring agricultural drought. In order to estimate the degree of agreement between index values and water balance dynamics, the graphical comparison between SPI and soil water balance was made for growing season in 2009 (Figure 3).

Results revealed best agreement between cumulative water deficit and SPI on the time scale of two months (SPI2). SPI2 was calculated for every day of vegetation season and compared with soil water balance for the reference crop. Daily values of soil water balance were calculated as a difference between precipitation and evapotranspiration cumulative for a period of two months. When the soil moisture deficit increased as a consequence of higher evapotranspiration rates, SPI2 wasn't capable to identify drought situations.

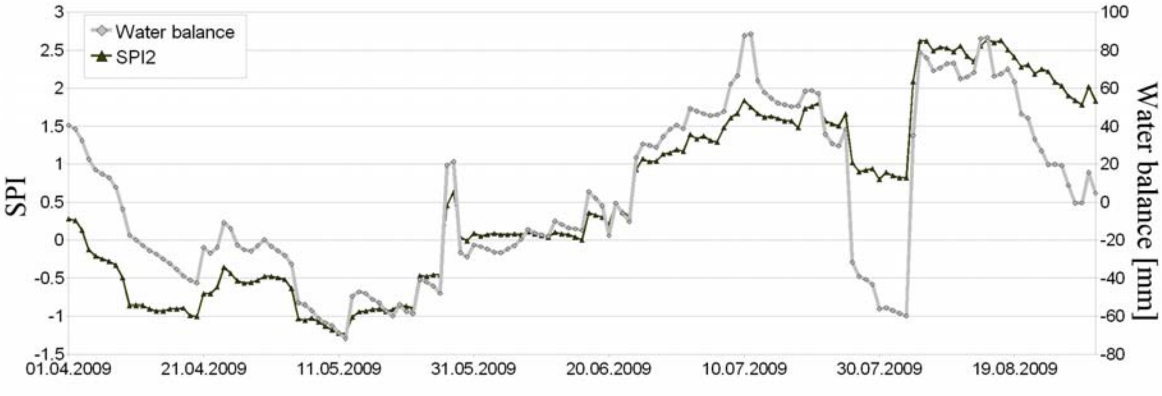

Figure 3: SPI values on the time period of two months (left y axis) and cumulative water deficit (right y axis) during vegetation period 2009 in Murska Sobota

Slika 3: Vrednosti indeksa SPI na dvomesečni skali (leva y os) in kumulativne vodne balance (desna y os) v vegetacijskem obdobju 2009 v Murski Soboti

This can be seen at the end of July, with a period of high water deficit, whereas SPI2 remained positive. Same situation occurred after an extreme precipitation event at the 4th of August, which was followed by the period of very hot weather with an occurrence of a heat wave. Thus, SPI solely couldn't explain the water balance dynamics in the root zone during periods, when soil moisture couldn't meet the plant needs.

3.3 Relationship between yield and different drought indicators

Crop yield at the harvest is a good indicator of climate, soil and management practices during the vegetation season.

Table 3: Correlation coefficients (r) among yield and drought indicators in the period 1983-2008 in Murska Sobota

Tabela 3: Koeficienti korelacije (r) med pridelkom in različnimi kazalniki suše za obdobje 1983-2008 v Murski Soboti

		P	ET_o	CWD	DS	SPI_6
Yield MS	Pearson Correlation	,462*	-,397	,652**	-,510*	,614**
	Sig. (2-tailed)	,027	,061	,001	,013	,001
	N	23	23	23	23	26

** Correlation is significant at the 0.01 level (2-tailed).

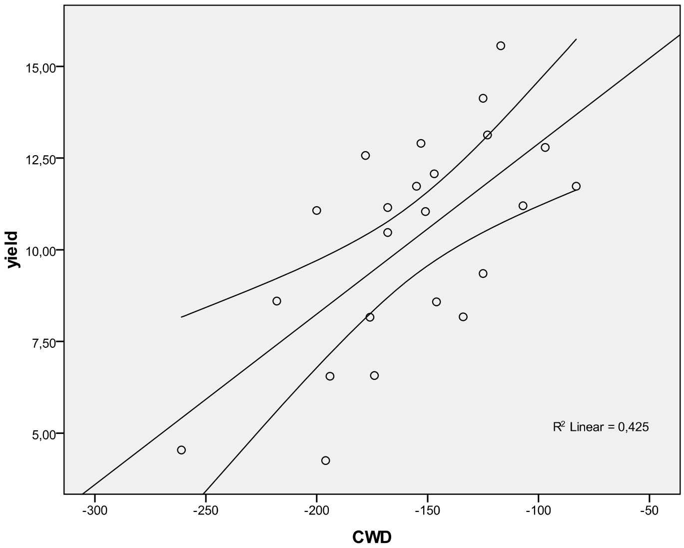

Figure 4: Yield vs. crop water deficit (CWD) for maize on soil with medium water holding capacity in Murska Sobota in the period 1983-2008

Slika 4: Pridelek v odvisnosti od primankljaja vode (CWD) za koruzo na tleh s srednjo zadrževalno sposobnostjo za obdobje 1983-2008 v Murski Soboti

Under standardized management practice routines and potential nutrition applications, climate determines the variability of crop yield for a certain soil type. SPI and model IRRFIB were used in order to investigate the effects of different indicators like precipitation (P), evapotranspiration (ET_o), crop water deficit (CWD) and drought stress (DS) on the maize yield over long-term period. Strong correlation is observed between yield and crop water deficit, whereas it was weaker with only one meteorological parameter like ET_o or P (Table 3). The correlation coefficients (r) between the crop water deficit and yield are significant indicating that higher crop water deficit lead to yield decrease (Figure 4).

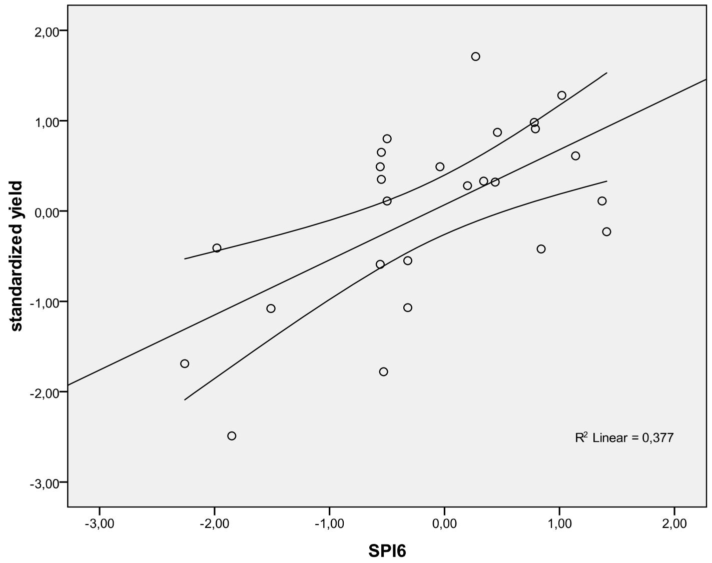

Figure 5: Standardized yield vs. standardized precipitation index on the time scale of 6 months (SPI6) in Murska Sobota in the period 1983-2008

Slika 5: Standardiziran pridelek v odvisnosti od indeksa SPI na šestmesečni skali za obdobje 1983-2008 v Murski soboti

Proxy data (drought impact reports) were also used for comparison due to the fact that long-term data on yield are unfortunately not available for Slovenia. The results showed that crop water deficit represents a good indicator when linking it with drought reports. Based on our understanding soil moisture can significantly affect the yield, but other factors like diseases and pests can trigger the decrease of yield as well (for example year 2005).

A comparison was also made between maize yield and SPI on different time scales.

In order to make a direct comparison with SPI, yield data were standardized for a period between 1983 and 2008. Best agreement was found between maize yield and SPI on the time scale of six months for September (Figure 5), which is in the time frame of maize growing season. There were significant differences in years with high temperature variability during growing season (Figure 6). Year 2006 shows highest disagreement; in that case the vegetation period was characterized by above normal precipitation (SPI value of 1.5), but the yield was below average. Lower yield was the consequence of high temperatures and low precipitation amounts during June and July. This is the period when maize is approaching tasseling and shows high degree of vulnerability to high temperatures and water deficiencies (Čergan et al., 2008). Large evapotranspiration rates during this period have limited potential development rate, which affected grain filling later in the season and consequently lowered the final yield.

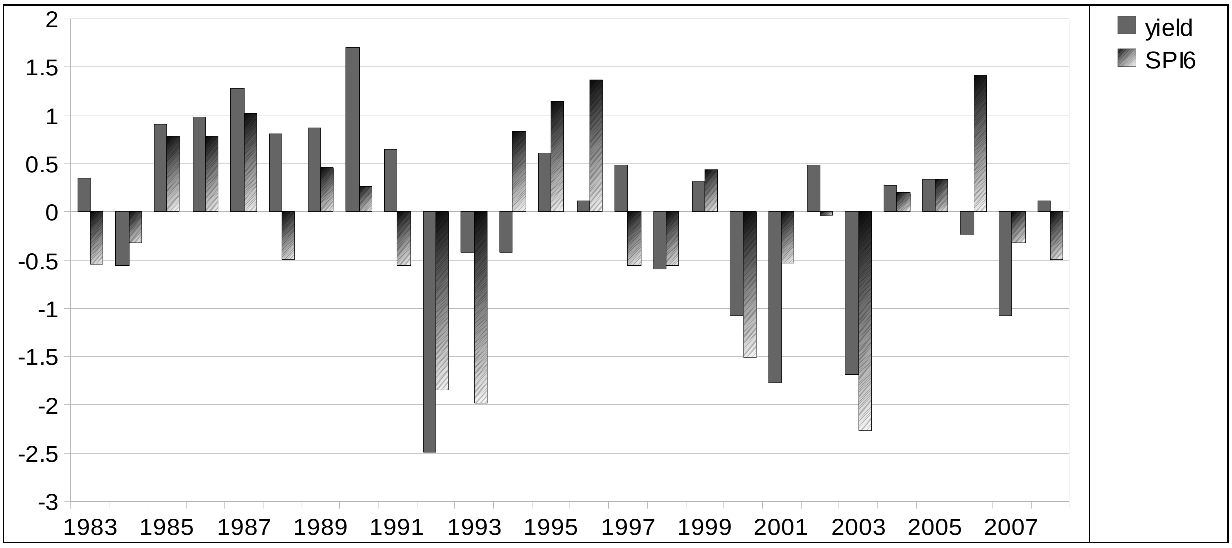

Figure 6: SPI on the time scale of 6 months and standardized maize yield in Murska Sobota in the period 1983-2008

Slika 6: Indeks SPI na šestmesečni skali in standardiziran pridelek koruze v Murski Soboti v obdobju 1983-2009

3.4 Crop water deficit as a measure of drought severity

In the end of this section we focused on the crop water deficit as a measure of drought severity. In order to investigate whether CWD is reliable in time before records of yield are available, we used CWD for the period of available phenological data for maize and meteorological data since 1971. The results show that the driest vegetation period in Murska Sobota occurred in 2003 (Figure 7). Very dry years were 1983 and 1993 and dry years 1984, 1988, 2000 and 2001 (Table 4).

Table 4: Percentile classes of crop water deficit (CWD) for maize on soil with medium water holding capacity in Murska Sobota in the period 1972-2008

Tabela 4: Percentilni razredi primanjkljaja vode (CWD) za koruzo na tleh s srednjo zadrževalno sposobnostjo za obdobje 1972-2008 v Murski Soboti

extremely dry	very dry	dry	normal	wet	very wet	extremely wet
< -237	**-237 to -198**	**-198 to -174**	**-174 to -107**	**-107 to -82**	**-82 to -70**	**> -70**
2003	1983	1984	1981	1973	1972	1975
	1993	1988	1985	1982	1980	
		2000	1986	1989		
		2001	1987	1997		
			1990	2005		
			1991			
			1994			
			1998			
			1999			
			2002			
			2004			
			2006			
			2007			
			2008			

The data have been checked with the reported drought impacts over a specified period of time. Drought impacts on cereals were confirmed in all extremely dry, very dry and dry vegetation seasons (HMZ / EARS, 1983-2003). The seasonal water deficit up to 240 mm was recorded in dry seasons (Table 4) in Murska Sobota.

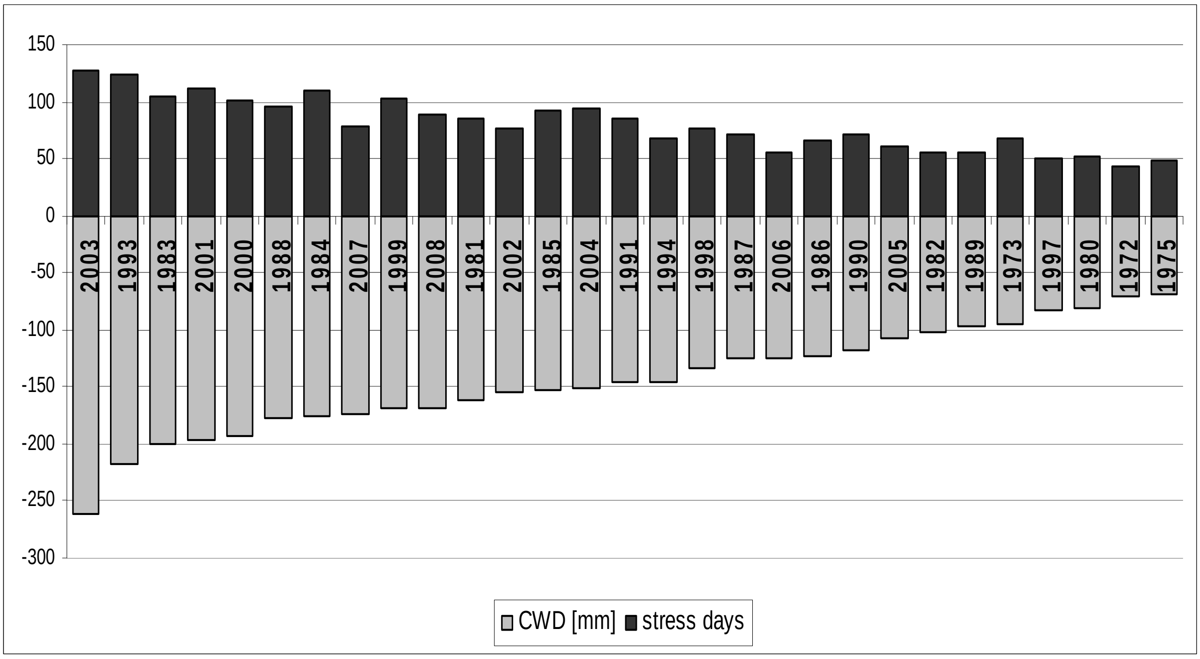

Figure 7: Crop water deficit (CWD) for maize on soil with medium water holding capacity in Murska Sobota in the period 1972-2008 in descending order

Slika 7: Primanjkljaj vode (CWD) za koruzo na tleh s srednjo zadrževalno sposobnostjo za obdobje 1972-2008 v Murski Soboti v padajočem vrstnem redu

3.5 NWP simulations as a tool for drought monitoring

Potential evapotranspiration and precipitation are among NWP simulated variables that are relevant for assessing drought conditions. It is known that numerical simulation of precipitation amount is among least reliable NWP output. This was confirmed by application of NMM numerical meteorological model on domain situated over SE Europe with approximately 8 km horizontal resolution; R^2 for 60-day precipitation accumulation of simulations, nested into ERA-Interim reanalyses (Simmons et. al., 2007) for stations in Slovenia haven't exceeded value 0.8 (in some cases it remained below 0.5), while in case of accumulation of evapotranspiration R^2 exceeded value 0.9 for all stations that were taken into account (Roškar and Gregorič, 2010). Overall performance of NWP model for drought monitoring is therefore promising; the question remains whether it is appropriate for drought impact assessment in local scale.

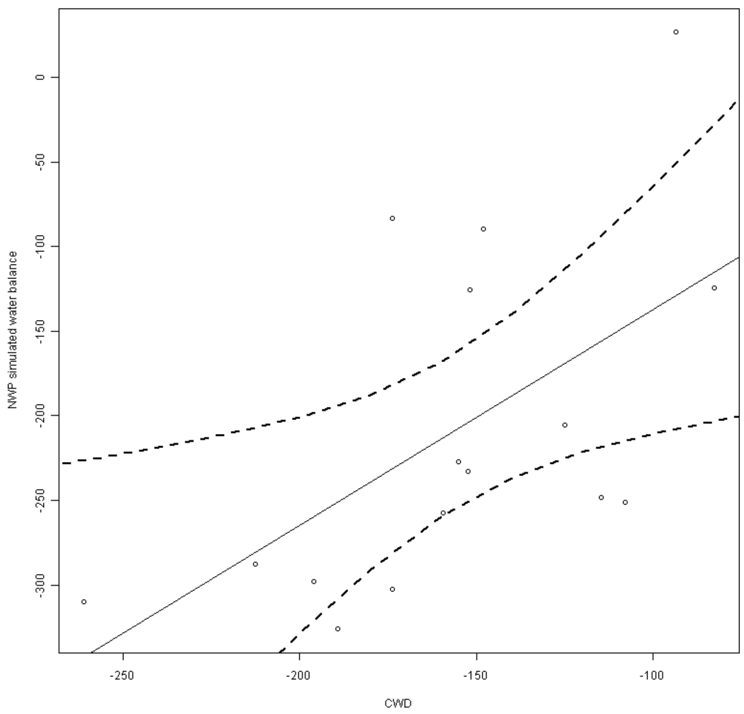

Figure 8: Comparison of maize crop water deficit in Murska Sobota with NWP simulations of surface water balance in the period 1989-2007

Slika 8: NWP simulacije površinske vodne balance v odvisnosti od primanokljaja vode (CWD) za koruzo za obdobje 1989-2007 v Murski Soboti

Table 5: Percentile classes of maize crop water deficit (CWD - see Table 4) and NWP simulated surface water balance in 5 percentile classes for years 1989-2008

Tabela 5: Razdelitev primankljaja vode za koruzo (CWD) in simulirane površinske vodne balance (NWP) v pet percentilnih razredov za obdobje 1989-2008

Year	**CWD**	**NWP simulation**
1989	extremely/very wet	extremely/very wet
1990	wet	normal
1991	normal	wet
1993	extremely/very dry	dry
1994	normal	normal
1997	extremely/very wet	wet
1998	normal	normal
1999	normal	wet
2000	dry	extremely/very dry
2001	dry	dry
2002	normal	normal
2003	extremely/very dry	extremely/very dry
2004	normal	normal
2005	wet	normal
2006	wet	normal
2007	normal	dry

Since CWD appears to be parameter that adequately represents local drought conditions, it can be used as measure of success of NWP simulation. Figure 8 shows comparison of modelled surface water balance (cumulative evapotranspiration subtracted from cumulative precipitation between May and September) to measurement-based calculation of CWD in period 1989-2007. Cumulative water balance between May and September was found to be closest parameter derived from NWP simulations using normal post-processing techniques to measurement-based CWD for maize. However, adjusted value of R^2 was only 0.29. Similar as in the case of SPI index, basic post-processing of NWP simulations could not explain significant part of interannual variability of drought stress estimated through CWD. This fact is presented also in Table 5 which contains measurement based CWD and NWP in percentile classes as in Table 4.

Only 5 percentile classes were used in this case (two most extreme classes on both sides were joined into single extreme wet or extreme dry class). In 7 years (out of total 16) the percentile classes don’t match. In 5 out of 7 cases there is “dry bias” of NWP derived water balance (in 1990, 2005 and 2006 “normal” opposed to “wet”; in 2007 “dry” opposed to “normal” and in 2000 “extremely dry” opposed to “dry”). In two cases (1991, 1999) “wet bias” was observed (“normal” opposed to “wet”).

4 DISCUSSION AND CONCLUSIONS

The following conclusions can be reached on the basis of above comparison and analysis:

(1) Water balance model IRRFIB simulations are of good quality. The relative difference of calibration results between IRRFIB and measurements is small (r = 0.8). In addition, model detection of crop water deficit, its drought stress and impact on yield is less consistent. In other words, CWD possess very micro-location capability.

(2) The yield decreases with the increase of CWD and DS. The fitting R-squares is 0.652 and 0.510, respectively. This indicates that CWD could represent drought conditions, while the fitting R-squares of P and ET_o are only 0.462 and 0.397, respectively. From the scatter points distribution of CWD dry years are confirmed with reported drought impacts. This is a clear demonstration of drought information for local scale and specific crop.

(3) Best agreement was found between maize yield and SPI on the time scale of six months for September, which is in the time frame of maize growing season. There were significant differences in years with high temperature variability during growing season. The SPI can be used to monitor conditions on a variety of time scales and is to be useful in both short-term agricultural and long-term applications.

(4) Comparison of NWP derived accumulated water balance to measurement based CWD indicates correlation to be rather poor (R-squared reaches values around 0.3 for various periods of accumulation). Although it is statistically significant at 0.01 level it is not possible to use NWP output directly to estimate drought impacts on crops. However, due to capability of NWP models to simulate temperature and evapotranspiration anomalies (and less successfully precipitation), there is potential to develop drought monitoring tools for regional scale.

(5) The integration of existing drought monitoring tools is essential for improving local and regional drought monitoring. A proactive approach emphasizing integration requires the collective use of multiple tools, which can be used to detect trends in crop water availability and provide early indicators at local, national, and regional scales on the likely occurrence of drought.

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