Application of the Self-calibrated Palmer Drought Severity Index for Estimation of Drought Impact on Maize Grain Yield in Pannonian Part of Croatia

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Abstract

Ten-day self-calibrating Palmer Drought Severity Index (scPDSI) has been computed, based on observed 10-day mean air temperature, relative humidity and precipitation totals, as a parameter of drought impact on grain yield of 32 market leading maize hybrids in 2017 and 2018 over 8 experimental locations in Pannonian part of Croatia. In addition, time series of the same climate variables for the closest "official" weather stations of Croatian Meteorological and Hydrological Service (DHMZ) for the period 1981-2018 have been used for scPDSI calibration and calculation. According to 10-day scPDSI, 2018 showed to be a „regular year" while 2017 had a „moderate drought" causing a maize grain yield reduction of 13%, compared to 2018. In spite some differences in climate aridity of central and eastern Croatia, a significant correlation between summer months' 10-day scPDSI and maize grain yield has been determined. The highest average correlation coefficients across all maize hybrids for three summer months were determined for the last decade (10-day period) of July and consecutive three decades in August. The dependence of grain yield on scPDSI value is not the same for all hybrids indicating various tolerances of different hybrids to drought stress. The grain yield reduction was primarily affected by insufficient grain filling (smaller 1000-kernel weight) and to some extent by reduction of number of grains. For practical use, within the set of given 32 tested hybrids, the level of determined drought tolerance of a hybrid has to be considered along with its relative grain yield performance.

1 Introduction

Since the maize is a leading crop in Croatia, which is predominantly grown without irrigation, along with looking for climate change adaptation options, an examination of currently cultivated maize hybrids to drought tolerance has a priority. More frequent appearance of dry years in several last decades because of the global climate warming will continue to rise and make a concern (Dai et al. 2004). Thus, a reliable estimate of intensity and duration of drought becomes essential in testing maize hybrids for their tolerance to drought. A review of drought indices is done in Zargar et al. (2011).

PDSI (Palmer Drought Severity Index) has been developed in the United States by Palmer (1965) addressing the intensity of dry and wet spells at their „beginning and ending times", developing a backtracking procedure to emphasize *meteorological drought* aspects (Alley 1984; Karl 1986; Dai et al. 2004). In addition, Karl (1986) considered application of intermediate term in the computation of the PDSI, the Palmer moisture anomaly index (Z-index), „which is more responsive on the short-term moisture deficiencies and better estimates forest fire danger and agriculture moisture shortages than the PDSI". However, Dai et al. (2004) shown that „the PDSI is good proxy of surface moisture conditions and streamflow", in spite a high simplicity of surface water balance hydrological model applied for calculation of PDSI. Authors emphasized less successful results in parts of China, Mongolia and former Soviet Union because of PDSI was calibrated for the central United States only. However, the last was solved by Wells (2002) and Wells et al. (2004) introducing scPDSI (self-calibrated PDSI) instead of PDSI. The weighting factors in the final equation for the scPDSI, called „duration factors", are calculated for each location separately. Schrier et al. (2006) applied scPDSI for the Europe and presented in their

Appendix A a review of scPDSI equations for backtracking. Soon latter, Schrier et al. (2007) applied scPDSI for drought analysis over Alpine region for the period 1800–2003. The authors included a simple snow accumulation and snow melting model in water balance calculation. Dai (2011) made a comparison of PDSI and scPDSI on a global scale, calculating Thornthwaite and Penman-Monteith potential evapotranspiration, respectively. He used a maximum length of 18 months for wet and dry spells in the regression equation for estimating the duration factors for the scPDSI calculation while Palmer (1965) used a length of dry spells of 48-months for calculation of PDSI. Dai's study indicated advantages of scPDSI against PDSI for the global scale, especially in arid and semi-arid areas. A group of Chinese authors, recently published a series of innovative papers related to the scPDSI, mostly devoted to Chinese territory. Liu et al. (2015) developed a new variant of scPDSI by coupling of Variable Infiltration Capacity (VIC) two layers surface hydrological model, described in details by Liang et al. (1994). By this Z-index bias, discussed also by Karl (1986), is restricted for semi-arid areas in China, but regional achievements have to be confirmed for the rest of the globe. Liu et al. (2016a) indicated that selection of sub-period in time series of climate data has some consequences on scPDSI while Liu et al. (2016b) studied influence of VIC model on scPDSI performance. Liu et al. (2017) made experiments with calculating scPDSI for short, medium and long time lengths of dry/wet spells in estimation of duration factors while Zhu et al. (2018) reached an improvement of scPDSI performances by coupling VIC model for short maximum lengths of dry/wet spellsof 10 months. A comprehensive punctual study of the drought in Pannonian part of Croatia has been done by Penzar (1976) using original Palmer (1965) procedure for calculation of PDSI for the period 1862–1973 for Zagreb Grič Observatory. As considered area, in that monography, has a mid-latitude continental climate, the PDSI results are rather consistent. They are representative at least for the central part of the northern Croatia (Pandžić et al. 2009; Pandžić et al. 2020). Mihajlović (2006) and Cindrić et al. (2016) used Standardized Precipitation Index (SPI) for study of the drought performance in Pannonian part of Croatia and detected more frequent droughts in the recent decades. Perčec et al. (2014) studied vulnerability to the drought in the area considered.

Global annual loss of maize yield due to drought is about 15%, which represents a damage of about $36 billion worldwide (Edmeades 2013). Typical visual symptoms of drought stress in maize are leaf rolling and senescence from the bottom up. Stress at flowering reduces seed set so drought-affected ears have fewer poorly filled kernels, and extremely severe drought can lead to the complete abortion of ears and the plant becomes barren (Edmeades et al. 2000). First basic requirement for genetic improvement progress in drought tolerance is identifiable and heritable genetic variation for grain yield, as the primary trait, but also some secondary traits such as larger number of grains per ear and larger grain weight (Bolanõs and Edmeades 1996; Betrán et al. 2003). A second basic requirement for successful breeding for drought tolerance is the availability of environments where stress intensity, timing and frequency can be reliably managed to expose genetic variation for traits season after season (Barker et al. 2005). Although it has been shown that selection under target stress can improve selection for such conditions (Bänzigeret al. 2004), difficulties in choosing the appropriate environment due to their great variability may limit the identification of superior genotypes. The response to selection is smaller in drought conditions compared to conditions without drought stress because of the relatively large genotype by environment interaction (GEI) and higher experimental error under random drought. When rely on occurrence of random drought, the ability to assess the level of drought stress of every experimental location in every year becomes essential in setting appropriate range of stressful locations in selection process.

Thus, in the context of massive maize production without irrigation, there is a challenge to “measure” the intensity and duration of drought within particular year and location for estimation the level of grain yield reduction caused by it. Also, it is a great challenge to assess the drought tolerance of particular maize genotypes (hybrids) within the given level of stress what would be very important for both, cultivar choice by farmers and strategy of breeding new cultivars. In the attempt to put more light on this problem, in this study we have estimated 10-day (decadal) scPDSI for maize growing seasons in 2017 and 2018 over eight experiment locations in the main maize production area of Croatia. At these locations, field trials with 32 maize hybrids representing four maturity groups have been performed in order to measure their grain yield and some related agronomic traits. The overall experimentwas assuming appearance of random drought at least on some locations and some years, as well as different performance (yield reduction) of particular maize hybrids under different levels of drought stress. Thus, objectives of this research were: (1) to analyze wider time span of drought episodes in Croatia by the 10-day scPDSI; (2) to test ability of 10-day scPDSI to measure drought during critical maize life cycle relevant for grain yield and to examine relationship between the values of 10-day scPDSI and maize grain yield and related traits, as well as (3) to investigate specific reaction (tolerance) of individual maize hybrids against various levels of drought stress.

2 Material And Methods

2.1 Climate in situ data

In this study, for the purpose of 10-day(decadal) and monthly PDSI and scPDSI values calculation, mean air temperature and relative humidity data as well as precipitation totals were computed out of data recorded by the automatic weather stations (AWS) installed within the field experimental locations across Croatia. These data were collected in a standard way for the period May-September 2017 and April-September 2018. In addition, time series of the same climate variables for the closest “official” weather stations of Croatian Meteorological and Hydrological Service (DHMZ) data for the period 1981–2018 have been used for drought indices calibration and calculation (Fig. 1).

Palmer’s procedure of PDSI and scPDSI calculation are represented in Appendix A while detailed calculation procedure of the same parameters for experimental locations in Croatia and some their statistical properties are described in the Appendix B.

2.2 Agronomic data

Thirty-two maize hybrids, belonging to maturity groups FAO 300 to 600, were evaluated in field experiments conducted in 2017 and 2018 at eight locations (L2-L6 and L8-L10) in northern Croatiain order to estimate a drought impact assessed by 10-day scPDSI on their agronomic traits (Fig. 1). Each of four maturity groups was represented by eight commercially relevant maize hybrids. Randomized complete block design (RCBD) with four replicates was used in all experiments. The size of 4-row experimental plots was 11.2 m^2, inter-row distance was 0.7 m and planting density was adjusted according to maturity groups. Cultural practices (tillage, fertilization, weed and pest control) in all experiments were carried out in accordance with the recommendations for the optimal production of maize.

Grain yield in all experiments was determined at the time of technological maturity by harvesting the middle two rows of each plot with special combine harvester. Grain yield (GY) was adjusted to 14% moisture and expressed as t/ha. Based on a sample of 10 random ears per plot, 1000-grain weight (TGW) was determined. The TGW was adjusted to 14% moisture and expressed in grams. Number of grains per m^2 (NoG) was calculated as grain yield divided by mass per grain.

Figure 1 Geographic position of 19 field experimental locations (L1–L19) and 11 reference DHMZ weather stations having historical climate data throughout territory of Croatia. This paper mostly deals with eight locations (L2 to L6 and L8 to L10) from the northern (Pannonian) part of Croatia (shown with pattern) which corresponds to the main maize growing area, (see Pandžić et al. 2020), (Graphical Platform: ArcGIS Desktop 10.7, Esri Inc.)

In the statistical analysis, each field experiment was treated as a single environment (location-year combination). Analysis of Variance (ANOVA) for agronomic data was performed across environments using General Linear Models (GLM) procedure of Statistical Analysis System - SAS (SAS Institute Inc. 2016). In order to estimate impact of drought intensity on agronomic traits environmental means for each hybrid were used to calculate the Pearson correlation coefficients *r* between 10-day scPDSI and agronomic traits grain yield, 1000-grain weight and grain number per m^2 using the CORR procedure of the SAS (SAS Institute Inc. 2016).

2.3 Satellite moisture products

Moisture of key months for growing seasons, from June to August of 2017 and 2018, were also analyzed by satellite images (represented in Fig. 4) using LSA SAF (Land Surface Analysis Satellite Application Facility) of EUMETSAT (European Meteorological Satellite) whose products are available at link: https://landsaf.ipma.pt/en/. Although other moisture availability products are available at LSA SAF portal, monthly totals of differences (in millimeters) between real evapotranspiration (*ET*) and hypothetical reference evapotranspiration (*ET0*) have been chosen. *ET0* refers to the area covered by green grass of 12 cm high without restriction of moisture availability and albedo of 0.23, during sunshine weather (Sepulcre-Cantoa et al. 2014).

3 Results And Discussion

3.1 Dryness/wetness of 2017 and 2018 growing seasons within the framework of the period

1981–2018

One of the goals of this paper was to apply “state of art” of scPDSI to measure moisture severity anomalies in 2017 and 2018 growing seasons taking into consideration also average moisture conditions during reference period 1981–2018. Climate moisture anomalies are rather well represented by 10-day scPDSI for all experimental locations during period 1981–2018 shown in Fig. 2. On this way an estimation of spatial and temporal severity of dry/wet spells, at least qualitatively, can be estimated. In addition to whole data set, for the period 1981–2018 represented in Fig. 2a, more detailed in time rescaled scPDSI subset for the period 2011–2018 is represented in Fig. 2b and finally, the most detailed presentation in Fig. 2c for the period 2017–2018.

From the Fig. 2a it can be concluded that the period 1981–1988 was prevailing wet, period 1989–1992 prevailing dry, period 1993–1999 was continuously wet, period 2000–2012 had exchange of dry and wet sub-periods and period 2013–2018 was prevailing wet. From the same figure, it is also visible that drought in 2012 was the most severe during period 1981–2018. Cindrić et al. (2016) and Pandžić et al. (2020) shown that 2012 year was the driest since 1862, i.e. from beginning of climate observations at Zagreb Grič Observatory located in Zagreb, capital of Croatia. From Fig. 2b the period 2011–2018 can be analyzed in more details than from Fig. 2a. Thus, it can be seen that part of 2011 and whole 2012 where extremely dry, 2013 was wetter than multiannual average, 2014 was extremely wet, 2015 was drier than average and 2016 was wetter than average. Growing season of 2017 was dryer than average while beginning of 2018 was wetter and its end dryer than average. Very detailed moisture anomaly analysis in 2017 and 2018 is visible from Fig. 2c. Growing season of 2017 was moderately dry especially in the coastal region where large forest fires hit that region but during growing season of 2018 near average conditions prevails with a wet period during previous winter season. Annual courses of 10-day scPDSI for Zagreb-Maksimir Observatory for four selected years (2012, 2014, 2017 and 2018) are shown in Fig. 3. In addition to an annual course of dryness/wetness during 2017 and 2018, respectively, these years are compared with the extremely dry 2012 (with a deficit of moisture) and extremely wet 2014 (with numerous floods in the area). The first 8 months of 2017 were moderately dry and last 4 months were wetter than average, while during 2018 the first 3 months where wetter than average, growing season near normal and the rest moderately dry. 10-day scPDSI for other experimental locations, at least in Pannonian part of Croatia, generally followed these patterns shown for Zagreb Maksimir Observatory. Considering all presented figures, it can be concluded that the level of drought as in 2017, appears in Croatia on average every 3–4 years.

Moisture of key months for growing seasons, from June to August of 2017 and 2018, analyzed by satellite images, is presented in Fig. 4. Moderately dryer conditions are obvious in Croatia for August 2017 (upper part of the figure on its right side) and less dry conditions for July but the least dry for the June of the same year (middle and left images in upper part of the Fig. 4), respectively. In general, June-

August period of 2018 was wetter than the same period in 2017 (down images in Fig. 4). More precisely, near normal moisture conditions prevailed in Pannonian part of Croatia during the same period of 2018 while August (and slightly July) was dryer than reference level for coastal region of Croatia.

3.2 Estimation of drought impact on maize grain yield

Another important goal of this paper was an attempt to estimate impact of moisture conditions on grain yield at eight experimental locations in Pannonian part of Croatia. Overall average grain yields (t/ha) for all of 32 cultivars are shown in Table 1. Yields for 2017 and 2018 are similar for locations in central Croatia (L2 to L4) while significant differences between the two years are observed for five locations in eastern Croatia (L5 to L10, without L7). Mean yield per ha over all locations is 1.62 t (13%) lower for moderately dry 2017 compared to rather normal 2018. However, when drought impact is compared for eastern locations only (L5 to L10, without L7), then mean yield loss raises up to 2.69 t (20%).

Table 1 Average maize grain yield (t/ha) of 32 maize hybrids for eight experimental locations in Pannonian part of Croatia for 2017 and 2018

	Experimental location								
Year	L2	L3	L4	L5	L6	L8	L9	L10	Mean
	t/ha								
2017	13.70	10.68	5.54	12.27	11.48	10.41	9.48	8.09	10.21
2018	13.45	10.26	5.70	14.48	15.37	12.50	11.29	11.55	11.83
Difference	-0.25	-0.42	0.16	2.21	3.89	2.10	1.81	3.46	1.62

These results might be partly explained by seasonal flow of multiannual averages of 10-day soil moisture availability and other conditions, including seasonal flow of climate variable multiannual averages for the period 1981–2018, used as reference (average) levels for scPDSI calculation in this study.

As cited in Appendix A, in wet climates during a part of a year evapotranspiration coefficients tend to be close to 1, while in dry climates they tend to be smaller. According to Palmer (1965), these coefficients are good measure of agricultural climate and indicate whether a particular area is suitable for maize production. Thus, analysis of represented in Fig. 5, for L2 experimental location from central Croatia and L5 from eastern Croatia, respectively, for summer months, stands in agreement with the results in Table 1. Coefficients are higher for L2 than for location L5 during summer months. Figure 6 depicts how coefficientsdecrease from the west to the east of Croatia for August. This agrees with results of Perčec et al. (2014) who found that locations in eastern part of Croatia are more vulnerable to drought than those in the central part are. From this can be concluded that moderate drought, measured by scPDSI as a relative index of moisture conditions, in the areas of rather wet climate (as central Croatia) has not a strong influence on maize grain yield, but in drier climate (eastern Croatia) that influence is stronger.

3.3 Relationship between 10-day scPDSI and agronomic traits

The combined ANOVA across environments (location-year combinations) revealed highly significant (P-value < 0.001) differences among environments (E), hybrids (H) as well as E×H interaction (Table 2). Environment had the largest effect, explaining 72%, 54% and 54% of the total sum of squares for grain yield, number of grains per m^2 and thousand kernel weight, respectively. Hybrid and E×H interaction explained similar proportion of total variation for grain yield and number of grains per m^2, while for thousand kernel weight variation is less affected by hybrid than by E×H interaction. The high proportion of sum of squares due to environment suggests a great variability of agro-ecological conditions in the conducted experiments including the effects of weather variables as well as differences among locations' soil characteristics.

Table 2 Analysis of variance for agronomic traits grain yield (GY), number of grains per square meters (NoG) and thousand kernel weight (TKW)

	GY (t/ha)		**NoG/m^2**		**TKW (g)**	
Source of variation	SS (%)	*P-value*	SS (%)	*P-value*	SS (%)	*P-value*
Environment (E)	72	< 0.001	54	< 0.001	54	< 0.001
Hybrid (H)	7	< 0.001	17	< 0.001	8	< 0.001
E×H	8	< 0.001	14	< 0.001	15	< 0.001

SS (%) – percent of the total sum of squares; *P – value* is compared here by a common alpha significance level of 0.001 (or 0.1 percent)

To examine the specific effect of drought on hybrid performance across environments we calculated Pearson correlations between 10-day scPDSI for 16 environments and corresponding values for agronomic traits in those environments. Correlation coefficients (*r*) between grain yield and 10-day values of scPDSI are generally low to moderate for June and first two decades of July, except for hybrids 9 and 25, which show higher values of *r* beginning from second and third decade of June, respectively (Table 3). From the third decade of July to the end of August *r* values are considerably higher compared to preceding period with the highest values for all hybrids appeared in the 3D of July. Hybrids 9 and 25 showed highest values of *r* over decades of all three summer months, which is an indication of their relatively higher susceptibility to drought in comparison to other hybrids. Mean correlation coefficients across hybrids between 10-day scPDSI and the two yield components indicate that 1000-kernel weight, showing generally higher values of *r* over 10-day periods, is more affected by drought than number of grains per m^2. This might be due to fact that flowering, fertilization, and grain setting have been completed for all hybrids up to middle of July in both years. Ao et al. (2020) have found that timing of moderate drought stress can influence number and size of kernels in various ways. In our study, correlation coefficients for the 1000-kernel weight followed the pattern observed for grain yield's correlation coefficients, showing comparable values in the critical decades to those observed for grain yield (Fig. 7).

Table 3 Pearson's correlation coefficients between grain yield and 10-day values of scPDSI in 16 trials for 32 maize hybrids

	June			**July**			**August**		
Hybrid	1D	2D	3D	1D	2D	3D	1D	2D	3D
FAO300									
1	0.27	0.34	0.34	0.29	0.33	**0.59**	0.45	**0.51**	**0.50**
2	0.22	0.30	0.32	0.27	0.39	**0.64**	**0.50**	**0.55**	**0.55**
3	0.06	0.15	0.15	0.11	0.23	**0.55**	0.36	0.38	0.35
4	0.11	0.25	0.27	0.24	0.35	**0.67**	0.48	**0.52**	**0.50**
5	0.36	0.44	0.47	0.44	0.47	**0.70**	**0.59**	**0.64**	**0.62**
6	0.15	0.28	0.28	0.24	0.36	**0.64**	0.47	0.49	0.48
7	0.29	0.38	0.38	0.32	0.34	**0.59**	**0.51**	**0.55**	**0.54**
8	0.33	0.45	0.45	0.41	0.46	**0.71**	**0.62**	**0.63**	**0.61**
FAO400									
9	0.39	**0.54**	**0.63**	**0.61**	**0.67**	**0.83**	**0.77**	**0.81**	**0.80**
10	0.20	0.32	0.33	0.28	0.37	**0.62**	0.47	**0.52**	**0.52**
11	0.14	0.25	0.21	0.16	0.24	**0.56**	0.40	0.44	0.45
12	0.21	0.30	0.29	0.26	0.33	**0.61**	0.46	**0.52**	**0.51**
13	0.27	0.36	0.35	0.31	0.33	**0.62**	0.47	**0.52**	**0.51**
14	0.25	0.36	0.36	0.32	0.36	**0.61**	0.44	0.49	0.49
15	0.22	0.30	0.28	0.24	0.27	**0.53**	0.38	0.44	0.42
16	0.25	0.42	0.43	0.38	0.42	**0.66**	**0.57**	**0.60**	**0.60**
FAO500									
17	0.23	0.31	0.41	0.40	**0.53**	**0.69**	**0.59**	**0.62**	**0.58**
18	0.18	0.26	0.32	0.29	0.44	**0.50**	0.41	0.45	0.46
19	0.13	0.25	0.29	0.26	0.39	**0.62**	**0.50**	**0.53**	**0.50**
20	0.12	0.20	0.24	0.22	0.34	**0.63**	0.48	**0.53**	0.49
21	0.20	0.28	0.28	0.25	0.35	**0.60**	0.46	**0.51**	0.49

Correlation coefficients in bold indicating that they are significant at significance level of P=0.05 (or 5 percent)

	June			July			August		
22	0.15	0.22	0.27	0.24	0.32	**0.53**	0.42	0.45	0.42
23	0.24	0.36	0.45	0.44	**0.53**	**0.69**	**0.61**	**0.64**	**0.59**
24	0.21	0.31	0.40	0.40	**0.54**	**0.66**	**0.56**	**0.59**	**0.56**
FAO600									
25	0.35	0.47	**0.57**	**0.56**	**0.62**	**0.74**	**0.65**	**0.69**	**0.67**
26	0.34	0.39	0.42	0.40	0.43	**0.64**	**0.53**	**0.58**	**0.54**
27	0.26	0.32	0.33	0.31	0.36	**0.59**	0.45	**0.50**	0.46
28	0.32	0.39	0.41	0.40	0.44	**0.61**	0.48	**0.54**	**0.52**
29	0.35	0.40	0.46	0.45	0.47	**0.50**	0.41	0.45	0.42
30	0.26	0.31	0.31	0.29	0.32	**0.55**	0.42	0.47	0.43
31	0.34	0.42	0.48	0.45	0.48	**0.60**	**0.51**	**0.54**	**0.51**
32	0.23	0.37	0.44	0.42	0.46	**0.68**	**0.60**	**0.61**	**0.57**
All hybrids	0.25	0.35	0.39	0.36	0.43	**0.65**	**0.53**	**0.57**	**0.55**

Correlation coefficients in bold indicating that they are significant at significance level of P=0.05 (or 5 percent)

It can be concluded that 10-day scPDSI, indicating cummulative moisture anomaly conditions, for the end of July and the whole August exhibit the strongest impact on maize grain yield but depending on maize hybrid. This arises from definition of scPDSI itself which expresses, jointly, current moisture conditions and previous moisture conditions at least during few previous months including period of the most critical phase of maize growing season what corresponds with early grain filling stage according to Meyer et al. (1993). For comparison see Pandžić et al. (2020).

The correlation coefficient between grain yield and scPDSI for third decade of July (most significant correlation from Table 3) for each hybrid was taken as an indicator of its tolerance to drought. To show relationship between drought tolerance of maize hybrids to their overall adaptability we plotted a scatter diagram between their *r* (July, 3D) and corresponding mean grain yield over 16 environments. This approach allows to divide genotypes into four tentative groups. The first group comprises hybrids with above average yield (> 11.02 t/ha) and above average drought tolerance (r < 0.62), the second group comprises hybrids with above average yield and below average drought tolerance, whereas two remaining groups comprised below average yielding hybrids with above and below average drought tolerance, respectively.

From the farmers' and maize breeding point of view, not only the hybrids with stable grain yield over water-stressed locations are desirable but also those with high overall grain yield performance. Even though hybrids 18, 3 and 11 (Fig. 8) showed lower sensitivity to water stress measured by scPDSI, they achieved below-average grain yield. On contrary, hybrids 5 and 23 showed rather high average grain yields but were more sensitive to drought stress at the same time. However, most desirable genotypes for farmers would be those showing above-average yield and below-average *r* coefficient (upper left corner). Different levels of drought tolerance for various maize hybrids in this study were expected to be due to different genetic background, as well as of different timing of stress across environments. This is in line with previous reports (Campos et al. 2006; Edmeades 2013).

4 Conclusions

Comparison of 10-day scPDSI data derived from official weather stations for the period 1981–2018 and analogue values derived from climate data collected within each experimental location during 2017 and 2018, enabled detection of “moderate drought” in 2017 and “vulnerability to drought” of locations in eastern part of Croatia. The satellite remote sensing images confirmed this as well. This level of drought appears in Croatia on average every 3–4 years.

The moderate drought in 2017 in the Pannonian part of Croatia had a different impact on maize grain yield in central part of Croatia vs. eastern one. The overall yield reduction in 2017 (compared to 2018) was 13% but in eastern part even 20% because of lower values of multiannual average real and potential evapotranspiration ratios i.e. lower multiannual average moisture availability in eastern than central part of Croatia during boreal summer months.

Moderate to strong significant correlations between 10-day scPDSI values and agronomic traits indicate ability of scPDSI to measure effects of drought on expression of important agronomic traits. The highest average correlation coefficients for all maize hybrids are for the last 10-day period in July and three 10-day periods in August. However, there are some deviations for particular hybrids. The lower detected correlation of a hybrid suggests its higher level of tolerance to drought what in combination with higher mean grain yield (over all locations) could determine its final value for cultivation. In general, the grain yield reduction was primarily affected by insufficient grain filling (smaller 1000-kernel weight) and to some extent by reduction of number of grains.

Declarations

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Conflicts of interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Author's Contribution

There are two aspects of the paper: climatological and agronomic aspect. DHMZ authors: Krešo Pandžić, Tanja Likso, Davor Tomšić and Nataša Strelec Mahović have been involved in climate related aspects in the paper: climate observation, data quality control and their analysis including satellite data. Faculty of Agriculture authos: Ivan Pejić, Hrvoje Šarčević, Marija Pećina and Ivana Šestak have been involved in agronomic related aspect in the paper: agronomic observation, these data quality control and their analysis. All authors participated in preparation of manusript as well.

Availability of data and material

Data and materials are available on a request.

Code availability

Code is available on a request.

Ethics approval

Submitted paper does not have any compromising content.

Consent to participate

The authors voluntarily agree to participate in this research study.

Consent for publication

The authors voluntarily agree that submitted paper be published in TAAC.

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Figures

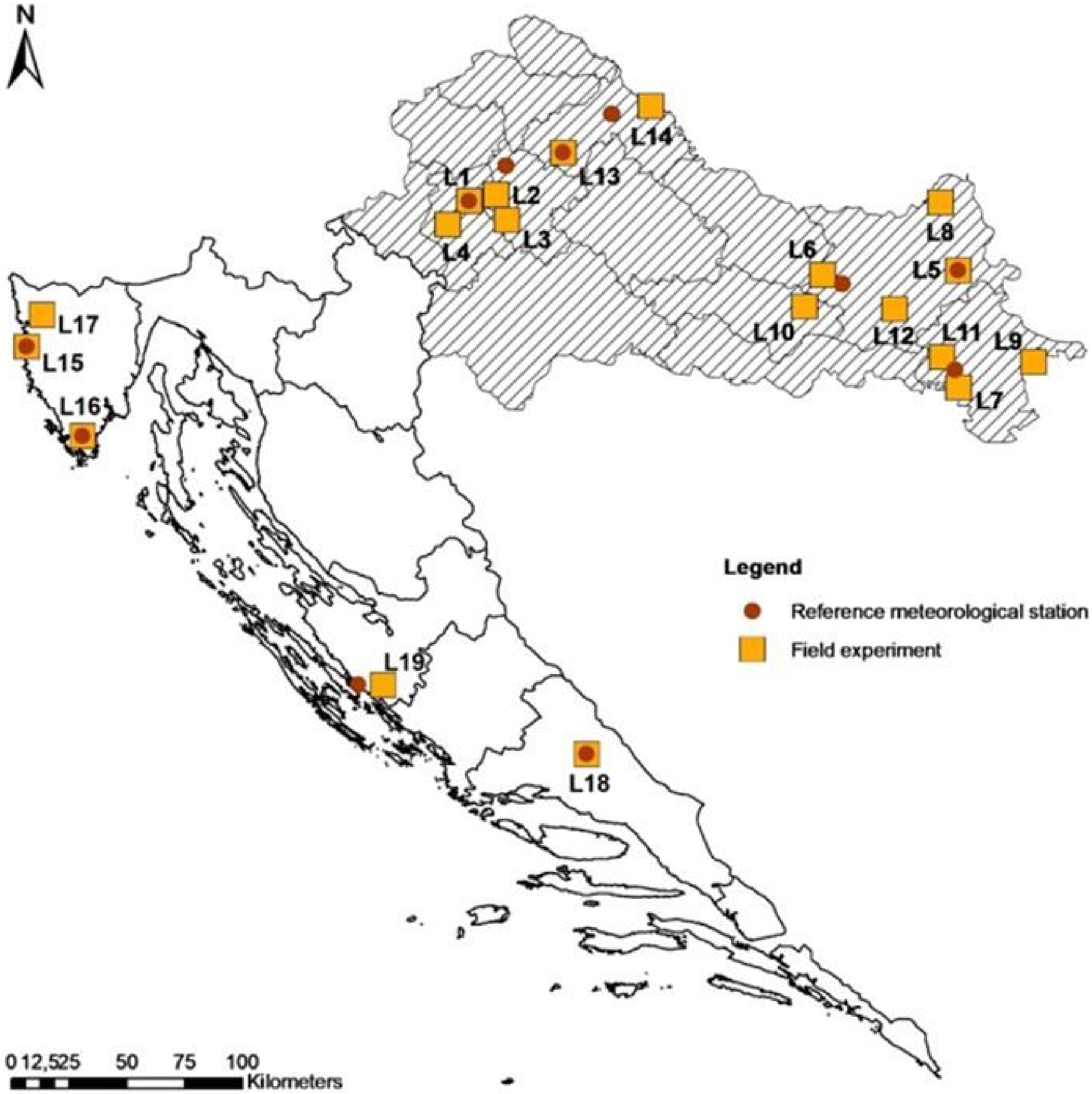

Figure 1

Geographic position of 19 field experimental locations (L1–L19) and 11 reference DHMZ weather stations having historical climate data throughout territory of Croatia. This paper mostly deals with eight locations (L2 to L6 and L8 to L10) from the northern (Pannonian) part of Croatia (shown with pattern) which corresponds to the main maize growing area, (see Pandžić et al 2020), (Graphical Platform: ArcGIS Desktop 10.7, Esri Inc.) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

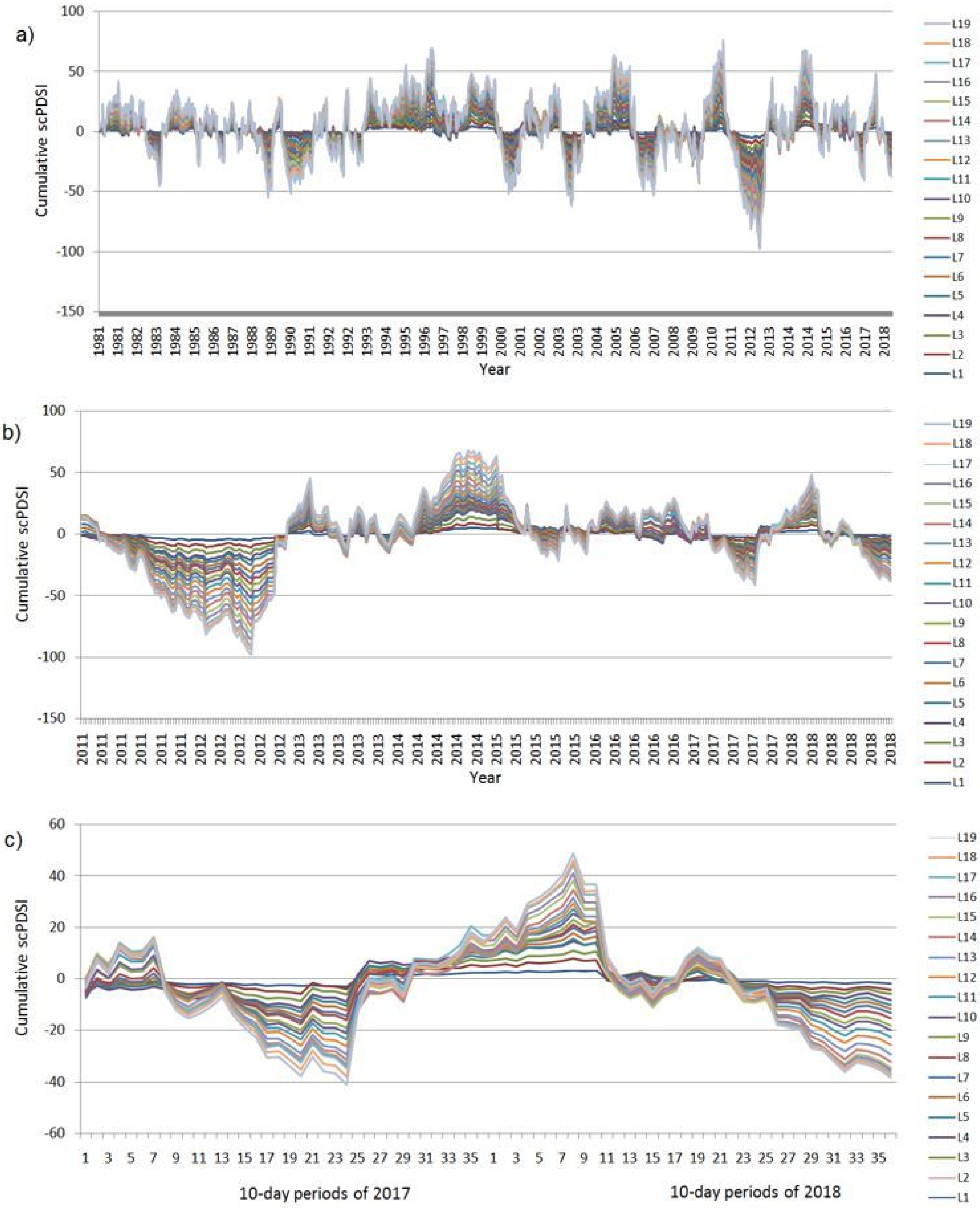

Figure 2

Cumulative option for graphical presentation of 10-day scPDSI for 19 experimental locations in Croatia for the periods: a) 1981-2018, b) 2011-2018 and c) 2017-2018

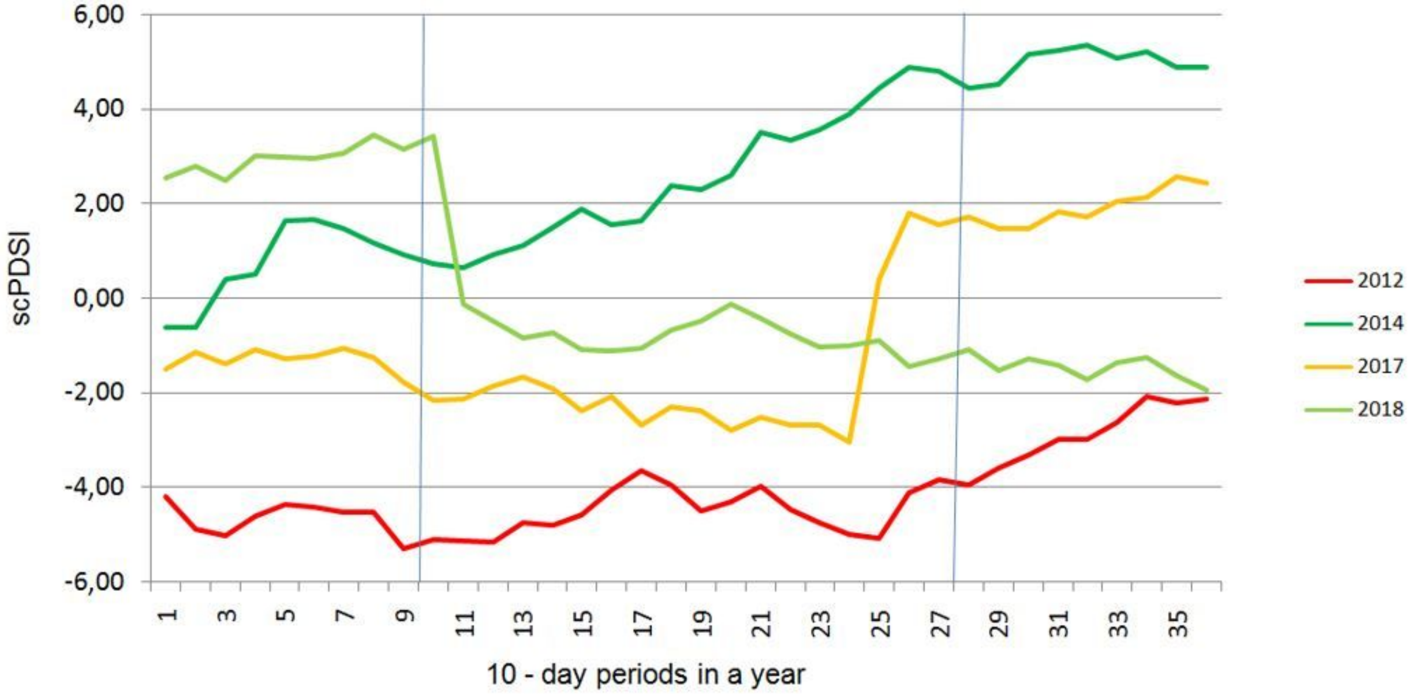

Figure 3

Comparison of extremely dry 2012 year and extremely wet 2014 with moderate dry 2017 and near normal 2018 based on 10-day scPDSI values. Two vertical lines indicate boreal vegetation period from April to September

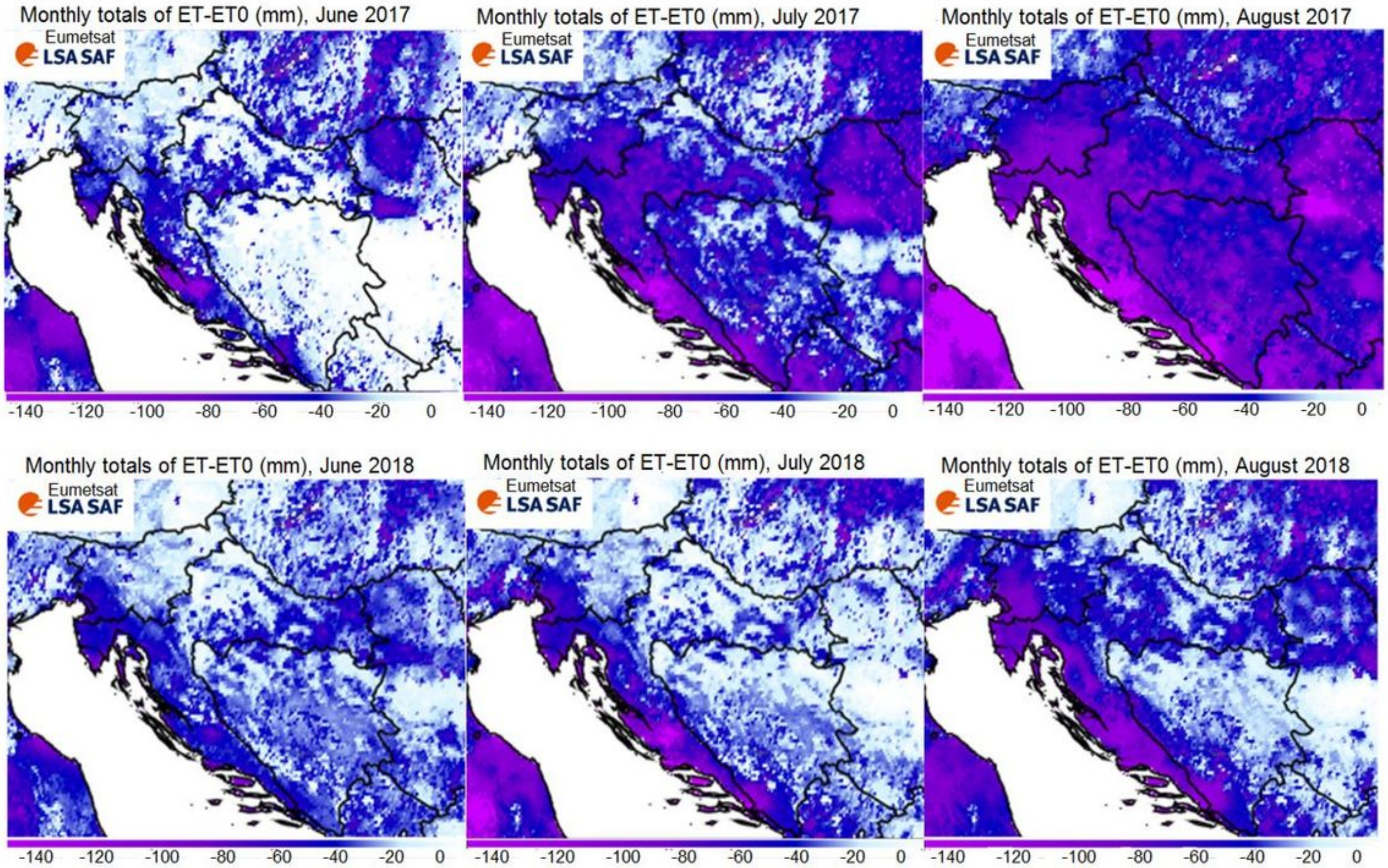

Figure 4

Eumetsat LSA SAF satellite images of wider area of Croatia for June, July and August in 2017 and 2018, respectively. Images represent monthly totals of differences (mm) between monthly totals of real evapotranspiration (ET) and corresponding reference evapotranspiration (ET0). According to LSA SAF of EUMETSAT (https://landsaf.ipma.pt/en/) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

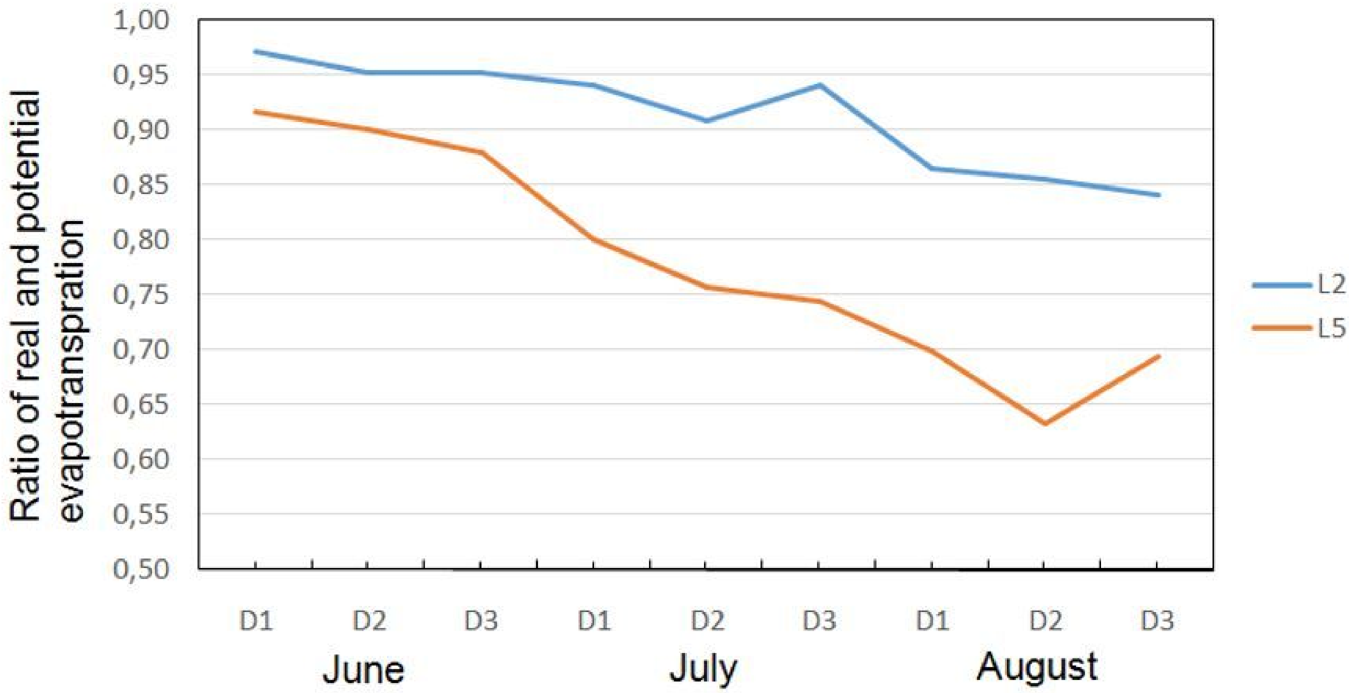

Figure 5

Average 10-day (D1,D2,D3) ratio of real and potential evapotranspiration, coefficient αi for June, July and August for to experimental locations L2 and L5 in Pannonian part of Croatia for the period 1981-2018

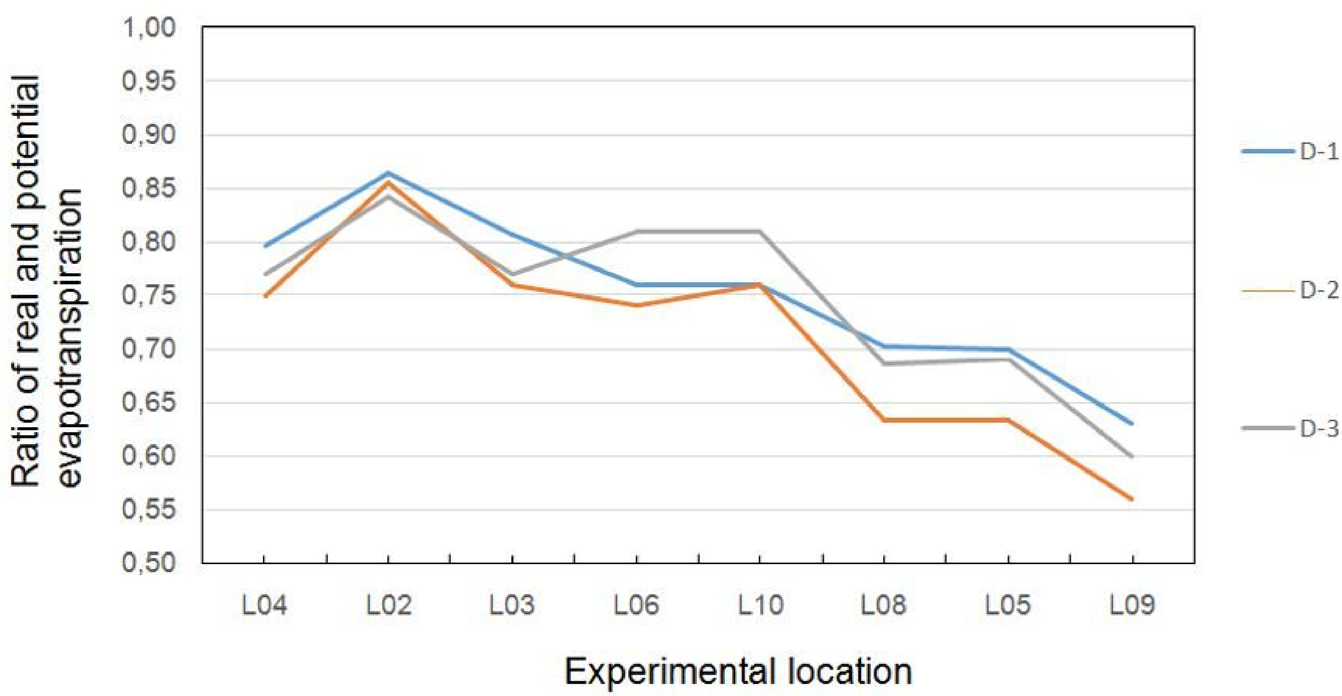

Figure 6

Average 10-day (D1,D2,D3) ratios of real and potential evapotranspiration for August for 8 experimental locations in Pannonian part of Croatia for the period 1981-2018

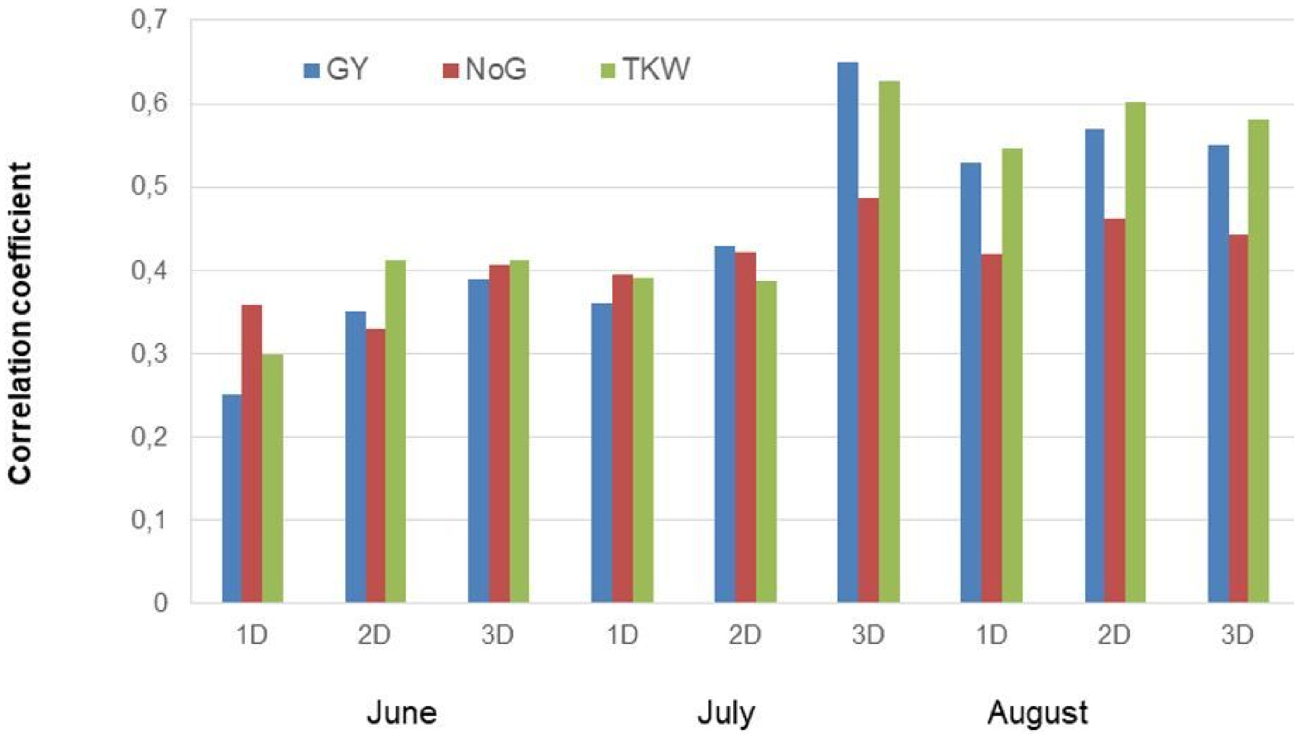

Figure 7

Correlation coefficients (mean over 32 maize hybrids) between 10-day scPDSI for summer months and agronomic traits grain yield (GY), number of grains per m2(NoG) and 1000-kernel weight (TKW) in 16 environments (8 experimental location in Pannonian part of Croatia in 2017 and 2018)

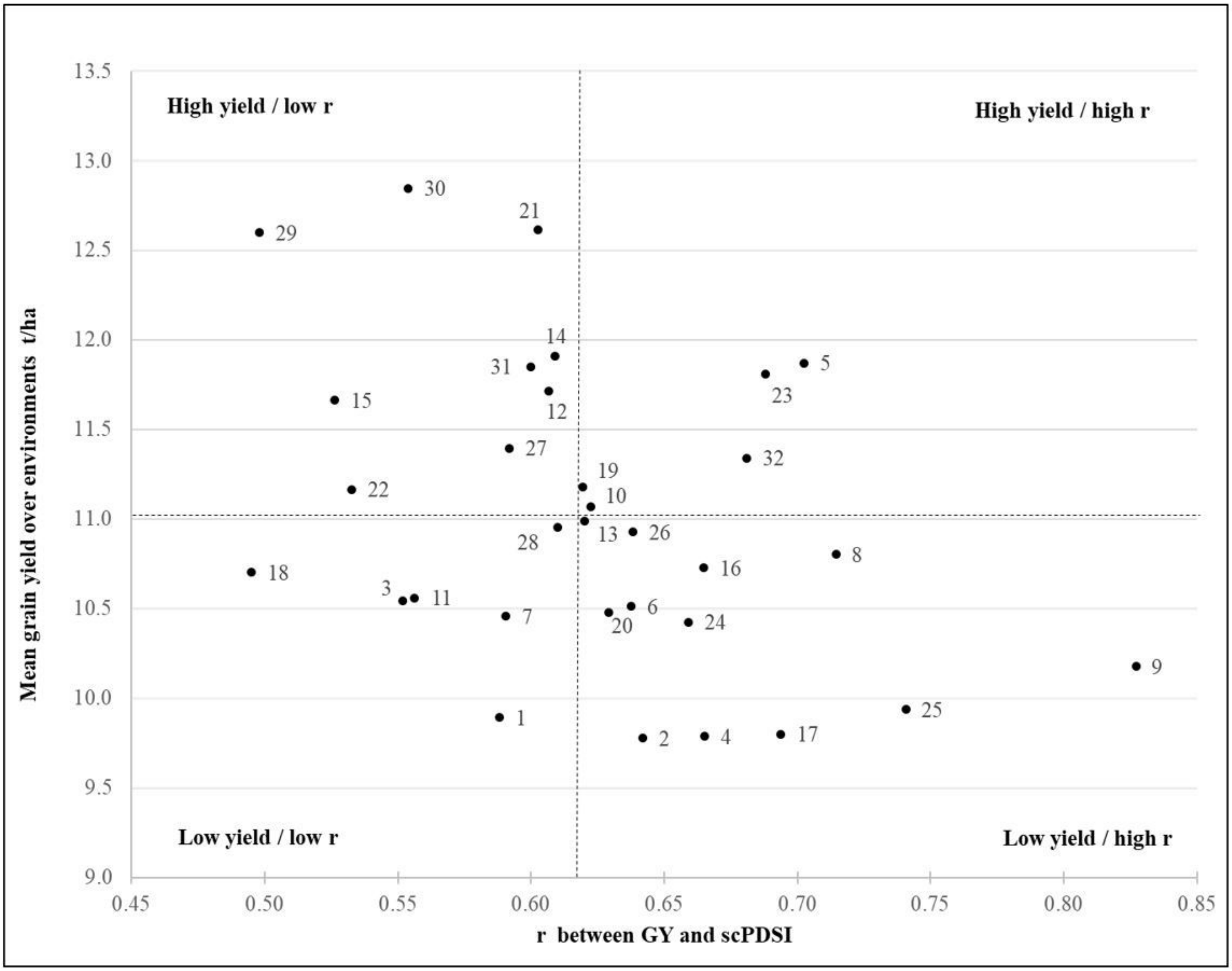

Figure 8

Mean grain yield (GY) over 16 environments in relation to correlation coefficient between GY and scPDSI for third decade (3D) of July

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- AppendixAB.docx
- AppendixFigureAB.docx