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The effect of soil and weather conditions on yields of winter wheat in multi-environmental trials

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SUMMARY

Drought reduces crop yields not only in areas of arid climate. The impact of droughts depends on the crop growth stage and soil properties. The frequency of droughts will increase due to climate change. It is important to determine the environmental variables that have the strongest effect on wheat yields in dry years. The effect of soil and weather on wheat yield was evaluated in 2018, which was considered a very dry year in Europe. The winter wheat yield data from 19 trial locations of the Research Center of Cultivar Testing (COBORU), Poland, were used. Soil data from the trial locations, mean air temperature (T) and precipitation (P) were considered as environmental factors, as well as the climatic water balance (CWB). The hydrothermal coefficient (HTC), which is based on P and T, was also used. The effect of these factors on winter wheat yield was related to the weather conditions at particular growth stages. The soil had a greater effect than the weather conditions. CWB, P, T and HTC showed a clear relationship with winter wheat yield. Soil data and HTC are the factors most recommended for models predicting crop yields. In the selection of drought-tolerant genotypes, the plants should be subjected to stress especially during the heading and grain filling growth stages.

Key words: climatic water balance, drought, growth stages, hydrothermal coefficient, precipitation, soil, air temperature

1. Introduction

Drought stress is one of the most important factors reducing crop yield (Ali and El-Sadek, 2016; Mueller et al., 2010). It affects all regions of the world, including Europe (García-León et al., 2019; Masante et al., 2018; Senapati et al., 2018). It is expected that droughts will occur with increasing frequency between May and August due to climate change, according to scenarios GISS Model E, HadCM3 and GFDL-R15 (Kuchar et al., 2015). Babushkina (2018) proved the significant increase of summer air temperatures since around 1970 in southern Siberia on the basis of long-term climatic data. For this reason it is urgent to investigate the most important environmental factors determining crop yields in conditions of dry weather. This would make it possible to predict (model) crop productivity more effectively and thus to select and recommend genotypes less susceptible to water deficits in particular periods and environments.

Various indices are used to identify and monitor drought, such as aridity index, hydrothermal coefficient, and others, based mainly on air temperature and precipitation (Svoboda and Fuchs, 2016). In Poland, the Agricultural Drought Monitoring System (ADMS) is based on Climatic Water Balance (CWB) (http://www.susza.iung.pulawy.pl; accessed 15 February 2019). CWB critical values for determining the occurrence of drought in a region depend on soil texture (agronomic category) and crop. The ADMS is used to identify drought-affected crop areas, which are listed in the "Act on subsidies for insurance of agricultural crops and farm animals" and are available online at http://www.susza.iung.pulawy.pl (accessed 15 February 2019).

Wheat is the world's third largest crop in terms of production (FAO, 2018), and winter wheat is the most important crop in Poland (GUS, 2018). The influence of climatic factors on spring wheat yields was examined by Babushkina et al. (2018) based on long-term data. The air temperature most frequently had a negative effect on yield until the stage of dough development due to excessive heat, and a positive effect during harvest. The impact of precipitation on yields was zone- and time period-specific; however, it was generally positive during heading, shortly before flowering.

Yu et al. (2018) examined the impact of droughts of different intensities on winter wheat yield during different growth stages. Significant negative effects on winter wheat yield were observed especially during the flowering and filling stages.

Carew et al. (2009) investigated the relationship between wheat yield and soil quality, cumulative air temperature and precipitation, fertilization and other factors in Canada for the years 2000–2007. A soil quality index was based on "historical yield data, soil characteristics and climate factors". It was computed by ranking all soil types on a scale from 1 (the least productive soils) to 10 (the most productive soils), and calculating an area weight for each production region. Soil quality was found to have a positive effect. Weather data included "growing season precipitation (between May 1 to July 31) and growing degree days (May 1 to August 31)". The interaction of rising air temperature and precipitation had a negative effect on spring wheat yields due to increased evapotranspiration.

In the Czech Republic, Káš et al. (2019) assessed the effect of precipitation and air temperatures on winter wheat yields in a 34-year long-term field trial at two sites. A positive effect of precipitation on yield was found at the site with better soils and a dryer and warmer climate. In contrast, a negative effect of precipitation and a positive influence of air temperature were observed on less fertile soils and in a more humid and cooler climate.

Currently, there are few studies concerning the effect of different soil and weather factors during particular growth stages on winter wheat yields. This information would be helpful to select environmental variables in models used to predict winter wheat yields depending on soil and climate conditions during the vegetation period. In breeding programs focused on the selection of drought-tolerant genotypes, it is important to induce dry conditions in the growth stage in which the crop is most susceptible to water deficit.

The objective of this study was to assess the effects of selected soil and weather variables and drought indices on winter wheat yield in multi-environmental trials.

2. Materials and methods

The data covered 19 trial locations of the Research Centre of Cultivar Testing (COBORU), Poland (Figure 1), observed in the Post Registration Variety Testing System (PVTS) during the 2017–2018 cropping season. The climate of all research stations can be described as warm temperate climate, fully humid with hot summer (Cfb), according to the Köppen–Geiger climate classification (Rubel and Kottek, 2010). However, the locations Marianowo, Węgrzce and Głubczyce are located close to areas of snow climate, fully humid with warm summer (Dfb) on the World Map of Köppen–Geiger Climate Classification based on observations from 1976–2000 (Rubel and Kottek, 2010).

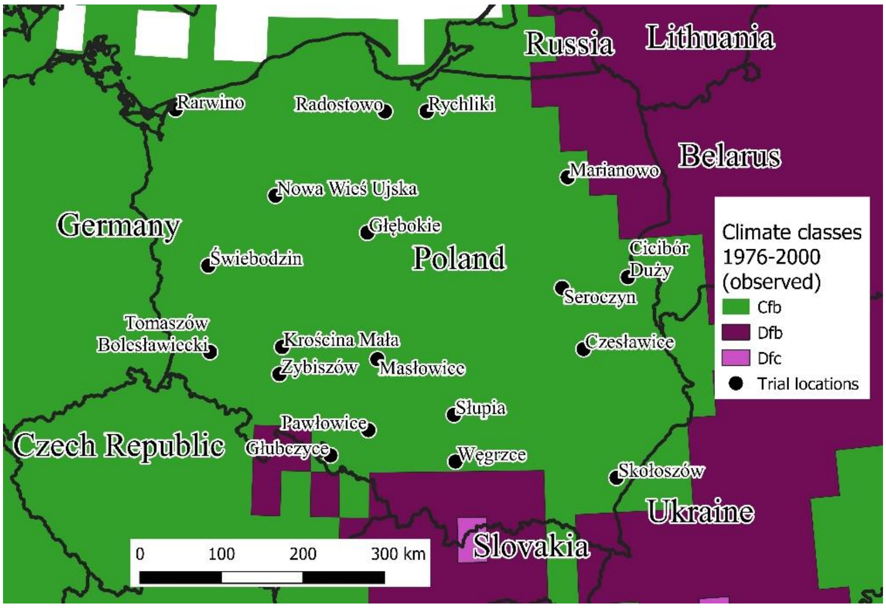

Figure 1. The 19 trial locations of the Post Registration Variety Testing System (PVTS) superimposed on the World Map of Köppen–Geiger Climate Classification (Rubel and Kottek, 2010). Cfb denotes warm temperate climate, fully humid with hot summer; Dfb denotes snow climate, fully humid with warm summer; Dfc denotes snow climate, fully humid with cool summer

Soil data from the trial locations were provided by COBORU. Arable land suitability (LS) was expressed in points (Table 1) according to Szewrański et al. (2017).

The environmental, weather and soil variables are shown in Table 1. Winter wheat grain yield, mean air temperature (T) and precipitation (P) were provided by COBORU. Each single record covered 10 days in each location. Both T and P were used for calculation of Selyaninov's Hydrothermal Coefficient (HTC) in 10-day periods. The climatic water balance (CWB) was obtained from the ADMS.

Table 1. Description of environmental variables used in the statistical analysis

Variable type	Variable name	Unit	Description and interpretation	No. per location	Source
Weather	Air temperature (T)	ºC	Mean air temperature in 10-day period	11	COBORU
	Precipitation (P)	mm	Sum of rainfall in 10-day period	11	
	Selyaninov Hydrothermal Coefficient (HTC)*	10 mm/ºC	HTC = 10 * ΣP / ΣT HTC values smaller than 1.3 indicate a water deficit, values higher than 1.3 and up to 1.6 indicate adequate water supply, and values higher than 1.6 indicate excessive water supply	11	Skowera and Puła (2004), simplified
	Climatic water balance (CWB)	mm	The difference between the precipitation and the potential evapotranspiration reported every 10-day period for a total period of sixty days	5	ADMS for the district in which the experiment is located
	Drought length (DL)	10-day period	The number of ADMS reports indicating the threat of drought between April 1 and July 10, adjusted to agronomic category	1	
Soil	Arable land suitability group (LS)	points	Arable land suitability for each trial location. The full scale ranges from 18 to 94 points, with higher values for better, more wheat-suitable soils (Szewrański et al., 2017).	1	COBORU
	Soil pH	unitless	Measured in 1 M KCl extract	1	

* Due to the type of data and very similar results, the HTC was identical to the Aridity Index (AI) (De Martonne, 1925; Baltas, 2007), which was not included in the paper. In this paper, the sum of air temperatures > 0 ºC was considered, differently than in Selyaninov's original HTC formula (Selyaninov, 1937)

The mean winter wheat grain yield data concerned a subset of the 29 cultivars which were studied in 2018 at each of 19 locations at two levels of crop management intensity: moderate (MIM) and high (HIM) (Studnicki et al., 2019). Information on the dates of winter wheat principal growth stages was provided by COBORU and rated according to Meier (1997), considering only the principal growth stages (e.g. 5), according to the BBCH (modified Zadoks) scale.

Table 2. The most important dates related to cropping and development of winter wheat

Location	Sowing	Tillering (BBCH_2)	Shooting (BBCH_3)	Heading (BBCH_5) *	Dough maturity (BBCH_8) *	Ripening (BBCH_9) *	Harvest
Rarwino	28/09/20	06/11/20	09/05/20	30/05/2018	25/06/2018	19/07/2018	22/07/20
Radostowo	17/10/20	06/04/20	30/04/20	01,03/06/2	08,10/07/2	31/07/2018	01/08/20
Rychliki	27/09/20	08/11/20	21/04/20	25,26/05/2	11,12/07/2	16,17/07/2	22/07/20
Marianow	29/09/20	05/11/20	08/05/20	27,28/05/2	02,04/07/2	14,16/07/2	24/07/20
Świebodzi	10/10/20	06/11/20	17/04/20	20,21/05/2	15,16/06/2	05,06/07/2	27/07/20
Nowa Wieś	28/09/20	15/11/20	30/04/20	28/05/2018	04/07/2018	18/07/2018	29/07/20
Głębokie	16/10/20	14/03/20	09/05/20	21,23/05/2	27,29/06/2	08,10/07/2	25/07/20
Masłowice	29/09/20	15/11/20	08/05/20	27,28/05/2	02,04/07/2	14/16/07/2	24/07/20
Seroczyn	29/09/20	03/11/20	20/04/20	21,22/05/2	23,25/06/2	07,09/07/2	24/07/20
Cicibór	02/10/20	17/11/20	09/05/20	18,21/05/2	26,27/06/2	09,10/07/2	02/08/20
Czesławice	29/09/20	31/10/20	20/04/20	21,22/05/2	no date	20,21/07/2	26/07/20
Krościna	02/10/20	30/11/20	10/04/20	15,17/05/2	18,20/06/2	02,04/07/2	27/07/20
Tomaszów	29/09/20	14/11/20	06/05/20	24,26/05/2	04,05/07/2	07,08/07/2	22/07/20
Zybiszów	10/10/20	20/11/20	16/04/20	20,22/05/2	28,30/06/2	09,11/07/2	25/07/20
Głubczyce	16/10/20	01/04/20	17/04/20	14,16/05/2	26,28/06/2	17,18/07/2	28/07/20
Pawłowice	17/10/20	26/03/20	19/04/20	20,21/05/2	26,27/06/2	12,13/07/2	24/07/20
Słupia	30/09/20	02/11/20	25/04/20	16,18/05/2	28,30/06/2	08,10/07/2	24/07/20
Węgrzce	12/10/20	15/03/20	25/04/20	14/05/2018	24,25/06/2	07,08/07/2	26/07/20
Skołoszów	05/10/20	06/11/20	02/05/20	29/05/2018	22/06/2018	no date	01/08/20

* The earlier date refers to moderate-input crop management, and the later date to high-input management

Statistical analyses were performed using Statistica 13.0 software (StatSoft, Tulsa, OK, USA). The Spearman's rank correlation coefficients between yield and the selected environmental variables were calculated. Diagrams showing the values of these coefficients (Figure 3) and the variation of weather conditions (Figure 2) during wheat growth were prepared using LibreOffice Calc (The Document Foundation) software.

3. Results

3.1. Weather conditions in the trial locations

In the majority of trial locations the heading stage was observed during the third 10-day period in May (Figure 2). Earlier occurrence of this stage (in the second period in May) was noted in Skołoszów, Węgrzce, Krościna Mała, Głubczyce and Słupia, and later occurrence (in the first period in June) in Radostowo (Figure 2). A general increase in air temperature during the vegetation period of winter wheat was observed in all trial locations in 2018. Exceptionally, a decrease in air temperature was noted in all trial locations in the third 10-day period in June, and in the second period in June in the majority of locations. The temporal distribution of precipitation differed depending on location. However, deficits of rainfall during/before the heading stage were observed in Głębokie, Nowa Wieś Ujska, Radostowo, Rarwino, Świebodzin and Tomaszów Bolesławiecki.

3.2. Variability of environmental variables

Summary statistics of environmental variables at the 19 trial locations are shown in Table S1 (supplementary material). The smallest CV was noted for CWB in April and May, then for air temperatures for all 10-day periods, and soil pH. The highest coefficients of variability were noted for LS, P in the second and first periods in June, HTC in the second and first periods in June, P in the third period in May, P in the second and first periods in April, and HTC in the same periods as for P. HTC variability was determined by P (higher variability) and not by T (small variability).

3.3. Correlations between environmental variables and winter wheat yield

The table of Spearman's rank correlation coefficients (Table S3) showed very strong relationships (r_s about 0.99 to 1.00) between HTC and P in all 10-day periods considered. CWB and winter wheat yield were also related in very a similar way to P and HTC, in contrast to T.

Arable land suitability (r_s = 0.61) had a strong and positive relationship with wheat yield, while the effect of pH was negligible (Figure 3, Table S2).

Wheat yields were negatively correlated with drought length (r_s = –0.40). Generally, precipitation and HTC affected wheat yield in a very similar way, while the effect of air temperature was the opposite (Figure 2, Table S3). From

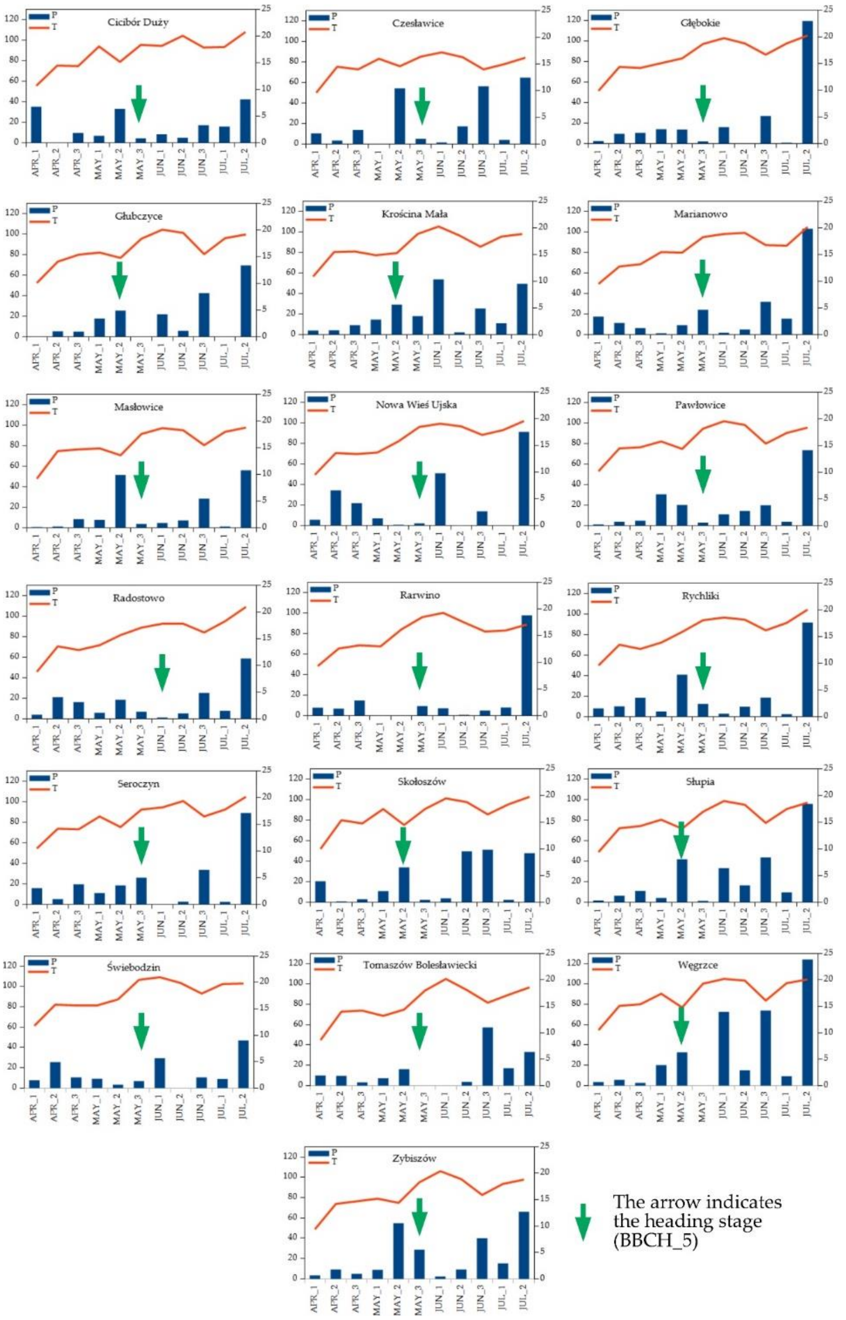

Figure 2. Weather conditions (precipitation and air temperature) during the growth and maturation of winter wheat at 19 trial locations in 2018

the beginning of the vegetation period until May 10 there was a negative or insignificant impact of precipitation and HTC, and a positive or insignificant impact of air temperature, on wheat yield. After May 10 the aforementioned factors were found to have the opposite effect on winter wheat yield.

Negative effects of precipitation and HTC on wheat yield were found in the first 10 days of April (r_s = –0.21 and r_s = –0.23 respectively) and in the first 10 days of May (r_s = –0.15 and r_s = –0.13 respectively). A weaker, positive effect of air temperature on wheat yield was found in the third 10-day period in April (r_s = 0.10) and in the first 10 days of May (r_s = 0.08).

A positive and strong effect of precipitation and HTC on wheat yield was found in the second 10-day period in May (r_s = 0.53 and r_s = 0.51 respectively) and in the second period in June (r_s = 0.48 and r_s =0.48 respectively). In the subsequent periods this influence was still positive, but weaker.

A negative effect of air temperature on wheat yield was found from the third 10-day period in May up to the third period in June, during the stage of grain filling (BBCH 7 and 8). This effect was particularly strong in the third 10-day periods in June and May (r_s = –0.29 and r_s = –0.23 respectively).

The relationship between CWB reported for 60 days and winter wheat yields was positive but usually weaker (r_s values between 0.16 and 0.32) than the relationship between yields and P, T and HTC in some 10-day periods.

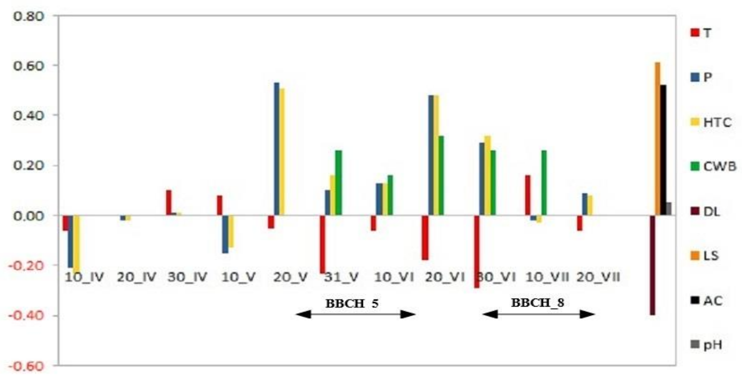

Figure 3. Correlation coefficients (0Y) between winter wheat yield and environmental variables (0X). The dates on the X-axis correspond to the last day of the time period considered (10-day period for T, P and HTC, and 60-day period for CWB)

4. Discussion

Soil conditions are among the most important factors determining wheat yields, as has been reported by Carew et al. (2009), Wójcik-Gront (2018) and Káš et al. (2019). The Polish classification of arable land suitability is related to soil texture (Jadczyszyn et al., 2016), and thus LS is strongly related to yields. The weak effect of pH on wheat yield resulted from the fact that it took favorable values for this crop (Table S1).

Wheat yields were negatively correlated with drought length, and this confirms the occurrence of drought as a yield limiting factor in Poland in 2018 (Masante et al., 2018).

Negative effects of precipitation and HTC on wheat yield were found in the first 10 days of April and the first 10 days of May (Figure 2, Table 3); this may indicate the occurrence of excess water in that period. Similar results were reported by Radzka and Jankowska (2015) in spring wheat. A weaker, positive effect of air temperature on wheat yield was found in the third 10-day period in April and the first period in May (Figure 3). The whole period between the first 10 days of April and the first 10 days of May corresponded to tillering (BBCH 2) and stem elongation (BBCH 3) in wheat, and despite the generally low rainfall during this time, the water deficit was probably not a growth limiting factor for wheat, due to the water reserves in the soil after the winter.

The period between May 10 and 31 was mostly the time of heading (BBCH 5) and flowering (BBCH 6), which is a critical period for winter wheat in terms of water supply (Hanson and Nelsen, 1980; Rane et al., 2007; Senapati et al., 2018). The influence of rainfall and HTC was especially strong in the period from May 10 to 20, which may be related to the increased variability of rainfall (Table S1). A similar positive effect of rainfall during the heading stage on wheat yields was reported by Babushkina et al. (2018) and by Radzka and Jankowska (2015).

A negative effect of air temperature on wheat yield was observed between the third 10-day period in May and the third period in June, during the stage of grain filling (BBCH 7 and 8). This result is consistent with the findings of Wheeler et al. (2000) on the negative effect of higher air temperatures during flowering on winter wheat grain formation and yield, as such air temperatures were in fact observed in the trial locations, especially in the first and second 10-day periods in June (Figure 2).

The importance of CWB for winter wheat yields was reported by Wójcik-Gront (2018) using data from seven growing seasons (from 2009/2010 to 2015/2016). However, as the CWB is reported in periods of 60 days, it is more difficult to refer it to crop growth stage. Moreover, it showed a weaker relationship with winter wheat yield than P, T, HTC and DL, and these indicators are more convenient for use in yield modeling and plant breeding programs.

HTC is calculated on the basis of P and T. As it replaces two values with one, it may be more convenient to use HTC rather than P and T in the models used for crop yield prediction. As an example, Table S4 gives HTC values, drought length, land suitability and winter wheat yield in particular locations of PDO trials. These locations are sorted in increasing order of yield. Lower yields were obtained most often on soils of lower suitability and in conditions of longer drought. Exceptionally, yield was low in Pawłowice (no drought and good suitability of land), Tomaszów Bolesławiecki (no drought), and Głębokie (good soils). HTC was higher in locations with higher yields, especially in the second 10-day period of May. This period is a time of heading (BBCH 5), flowering (BBCH 6) and initial grain development (BBCH 7), which are critical for cereals in terms of water supply (Hanson et al., 1980).

5. Conclusions

Soil conditions had a greater impact on yields than weather conditions. Lower yields (between 3 t/ha and 8 t/ha) were most frequently obtained on soils of lower suitability (most frequently with values not exceeding 70) and in conditions of longer or more frequent drought periods, particularly near to the heading stage (BBCH 5). Higher yields (8 t/ha and more) were obtained on soils of higher suitability (most frequently evaluated at 80 or more points), in locations in which drought did not occur or occurred for a shorter time.

CWB, HTC, P and T, all showed a clear relationship with winter wheat yield. CWB is presented for a 60-day period and is difficult to relate to particular growth stages. HTC, P and T are easier to associate with the growth stage of crops, but HTC is more suitable because it combines rainfall and air temperature within one variable. Consequently, in models predicting crop yields depending on climate conditions during the vegetation period, it is primarily recommended to use HTC and soil data.

The strongest effect of drought stress on yield was observed in the period during or shortly before heading (BBCH 5), and then during grain filling (BBCH 7). Thus, in breeding programs focused on the selection of drought-tolerant genotypes, the stress conditions should be induced during these stages.

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Supplementary Materials

Table S1: Summary statistics of environmental variables used in the statistical analysis;
Table S2: Spearman's rank correlation coefficients between winter wheat yield and soil variables and drought length;
Table S3: Spearman's rank correlation coefficients between winter wheat yield and weather variables included in the study;
Table S4: Hydrothermal coefficient in particular 10-day periods, drought length, land suitability and winter wheat grain yield in particular locations of PDO trials.

Table S1. Summary statistics of environmental variables used in the statistical analysis

Variable	Unit	Period	Min–max	Mean	Median	CV(%)
		1 – 10 April (APR_1)	8.6 –11.8	9.9	9.6	8.08
		11 – 20 April (APR_2)	12.6 – 15.8	14.2	14.2	5.63
		21 – 30 April (APR_3)	12.7 – 15.6	14.3	14.3	6.29
		1 – 10 May (MAY_1)	13.0 – 18.1	15.3	15.5	9.15
		11 – 20 May (MAY_2)	13.6 – 16.8	15.0	14.8	5.33
T	℃	21 – 31 May (MAY_3)	16.4 – 20.5	18.2	18.3	4.95
		1 – 10 June (JUN_1)	17.2 – 21.0	19.2	19.3	5.21
		11 – 20 June (JUN_2)	16.3 – 20.1	18.7	18.8	4.81
		21 – 30 June (JUN_3)	14.0 – 17.9	16.2	16.2	5.56
		1 – 10 July (JUL_1)	15.0 – 19.7	17.8	18.0	6.18
		11 – 20 July (JUL_2)	16.2 – 21.0	19.3	19.6	6.22

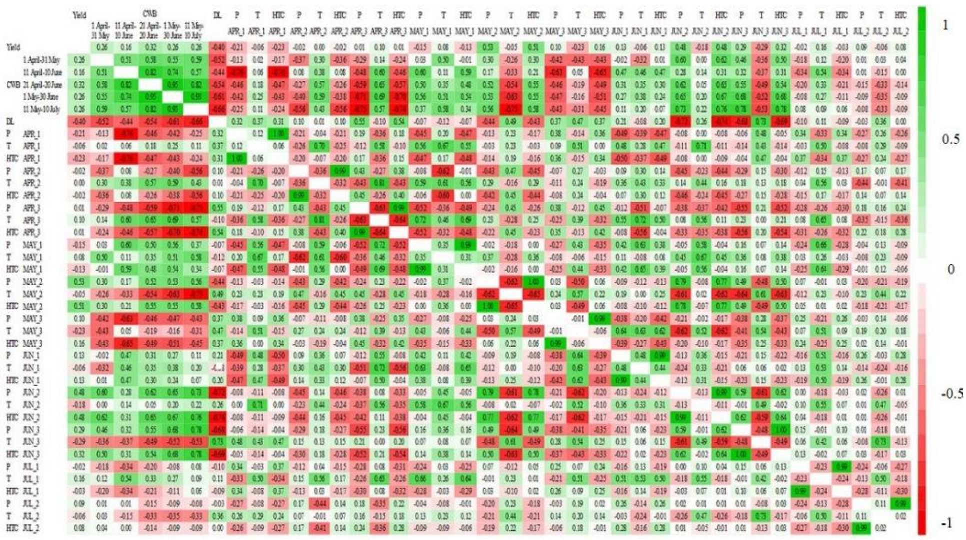
Variable	Unit	Period	Min–max	Mean	Median	CV(%)
P	mm	1 – 10 April (APR_1)	0.2 – 35.1	8.3	5.5	102.41
		11 – 20 April (APR_2)	0.0 – 34.2	8.5	5.6	103.53
		21 – 30 April (APR_3)	2.6 – 21.7	10.1	9.6	56.44
		1 – 10 May (MAY_1)	0.0 – 30.4	9.6	7.6	76.04
		11 – 20 May (MAY_2)	0.0 – 54.9	26.2	25.4	64.50
		21 – 31 May (MAY_3)	0.0 – 28.8	8.2	4.3	109.76
		1 – 10 June (JUN_1)	0.0 – 70.2	16.9	7.0	123.67
		11 – 20 June (JUN_2)	0.0 – 49.7	8.9	5.1	124.72
		21 – 30 June (JUN_3)	5.0 – 73.9	32.7	28.3	53.82
		1 – 10 July (JUL_1)	0.0 – 17.1	7.1	7.6	78.87
		11 – 20 July (JUL_2)	33.1 – 124.2	74.9	69.7	34.58
HTC	unitless	1 – 10 April (APR_1)	0.0 – 3.3	0.8	0.6	100
		11 – 20 April (APR_2)	0.0 – 2.5	0.6	0.4	100
		21 – 30 April (APR_3)	0.2 – 1.6	0.7	0.7	57.14
		1 – 10 May (MAY_1)	0.0 – 1.9	0.6	0.5	66.67
		11 – 20 May (MAY_2)	0.0 – 3.8	1.8	1.7	66.67
		21 – 31 May (MAY_3)	0.0 – 1.4	0.4	0.2	100
		1 – 10 June (JUN_1)	0.0 – 3.6	0.9	0.4	111.11
		11 – 20 June (JUN_2)	0.0 – 2.6	0.5	0.3	120.00
		21 – 30 June (JUN_3)	0.3 – 4.6	2.1	1.8	57.14
		1 – 10 July (JUL_1)	0.0 – 1.0	0.4	0.4	75.00
		11 – 20 July (JUL_2)	1.8 – 6.2	3.9	4.0	33.33
CWB	mm	1 April – 31 May	-179.8 – -144.2	-158.8	-159.6	0.63
		11 April – 10 June	-209.3 – -142.8	-180.3	-182.3	10.48
		21 April – 20 June	-223.3 – -122.1	-185.0	-194.5	16.22
		1 May – 30 June	-245.5 – -60.6	-159.8	-158.9	33.23
		11 May – 10 July	-249.3 – -77.5	-165.4	-174.6	27.69
DL	10-day periods		0 - 5	1.6	2	106.25
LS	points		52 - 94	77.3	80	139.72
Soil pH	unitless		4.9 – 7.0	6.1	6.1	8.20

Table S2. Spearman's rank correlation coefficients between winter wheat yield and soil variables and drought length

	Yield	LS	Soil_pH	DL
Yield		0.61	0.05	-0.40
LS	0.61		0.16	-0.66
Soil_pH	0.05	0.16		-0.13
DL	-0.40	-0.66	-0.13	

*values marked red indicate significant strong negative correlation, and values marked green indicate significant strong positive correlation

Table S3. Spearman's rank correlation coefficients between winter wheat yield and weather variables included in the study



Green and red shades represent strong positive and strong negative correlations, and the intensity of shading represents various levels of significance

Table S4. Hydrothermal coefficient in particular 10-day periods, drought length, land suitability and winter wheat grain yield in particular locations of PDO trials

Location	APR 1	APR 2	APR 3	MAY 1	**MAY 2**	**MAY 3**	**JUN 1**	JUN 2	JUN 3	JUL 1	JUL 2	DL	Yield mean	LS
Tomaszów Bolesławiecki	1.2	0.7	0.2	0.5	1.1	**0.0**	0.0	0.2	3.6	1.0	1.8	0	3.3	52
Pawłowice	0.1	0.2	0.3	1.9	1.4	**0.1**	0.6	0.8	1.3	0.2	4.0	0	4.9	80
Seroczyn	1.5	0.4	1.4	0.7	1.3	**1.3**	0.0	0.1	2.0	0.1	4.4	4	5.6	70
Głębokie	0.2	0.7	0.7	0.9	0.9	**0.1**	0.8	0.0	1.6	0.0	5.9	2	5.7	80
Cicibór Duży	3.3	0.0	0.7	0.4	2.2	**0.2**	0.5	0.2	1.0	0.9	2.0	4	5.7	70
Nowa Wieś Ujska	0.6	2.5	1.6	0.5	0.0	**0.1**	2.7	0.0	0.8	0.0	4.7	5	6.1	70
Rarwino	0.8	0.5	1.1	0.0	0.0	**0.5**	0.4	0.0	0.3	0.5	5.7	2	6.7	70
Świebodzin	0.6	1.6	0.7	0.6	0.2	**0.3**	1.4	0.0	0.6	0.5	2.4	4	6.9	70
Masłowice	0.1	0.1	0.6	0.5	3.8	**0.2**	0.2	0.4	1.8	0.1	3.0	2	7.3	70
Marianowo	1.8	0.1	0.5	0.1	0.6	**1.2**	0.1	0.3	1.9	0.9	5.1	2	7.5	70
Skołoszów	2.0	0.1	0.2	0.6	**2.3**	0.1	0.2	2.6	3.1	0.1	2.4	0	8.7	80
Węgrzce	0.3	0.4	0.2	1.2	**2.2**	0.0	3.6	0.8	4.6	0.5	6.2	0	8.9	94
Rychliki	0.8	0.7	1.4	0.4	2.6	**0.6**	0.2	0.5	1.1	0.1	4.6	2	9.1	80
Krościna Mała	0.4	0.3	0.6	1.0	**1.9**	0.9	2.7	0.1	1.5	0.6	2.6	3	9.6	70
Czesławice	1.1	0.2	1.0	0.0	3.7	**0.3**	0.1	1.1	4.0	0.3	4.0	0	9.9	94
Zybiszów	0.4	0.6	0.3	0.6	3.8	**1.4**	0.1	0.5	2.5	0.8	3.5	0	9.9	80
Radostowo	0.4	1.5	1.2	0.4	1.2	0.4	**0.1**	0.3	1.5	0.4	2.8	0	10.0	94
Głubczyce	0.0	0.4	0.3	1.1	**1.7**	0.0	1.1	0.3	2.7	0.0	3.6	0	10.2	94
Słupia	0.2	0.5	0.8	0.3	**3.0**	0.1	1.7	0.9	2.9	0.5	5.1	0	10.5	80

*bolded and marked yellow: HTC values during the heading stage

The HTC values marked red lower than 0.7, and those marked orange closer to 1.3, indicate water deficit; values marked green between 1.4 and 1.6 indicate adequate water supply; values above 1.6 marked blue and marked dark blue indicate excessive water supply (based on Skowera and Puła, 2004, simplified).

The DL ranges from zero ADMS reports concerning a threat of drought, marked green, to 1–3 reports, marked orange, and 4–6 reports, marked red.

Mean yield is presented from minimum 3 marked red to maximum 4–7 marked green.

LS: the results in points range from 52 to 94, with smaller numbers for the lowest soil suitability (marked orange) and larger for the highest suitability (marked dark green)