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SIMULATION OF TEMPERATURE INCREASE INFLUENCE ON WINTER WHEAT YIELDS AND DEVELOPMENT IN SOUTH – EASTERN ROMANIA

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ABSTRACT

Understanding the long term impact of temperature changes on phenology, yield and stability yield of wheat is important for establishing correct breeding goals. Weather data from 1991-2008, representative for South Eastern Romania were used to determine the DSSAT cultivar dependent coefficients for vernalization and photoperiod requirements and the grain filling duration providing a top average yield combined with the best yield stability. Cultivars with low sensibility for photoperiod (P1D = 25) and rather high requirement for vernalization (P1V = 45) had the best stability for high yields for all three tested values (400, 500 and 600) for the P5 coefficient (controlling the grain fill duration). If an arbitrary increase of temperature with 1°C is applied, the yield stability of these ideotypes increased significantly, but for an increase with 2°C an increase of vernalization requirements is suggested for the cultivars with shorter grain filling period (P1D = 25, P1V = 60, P5 = 400) and for cultivars with mid and longer grain filling period a high yield stability was given by a low to moderate value for photoperiod coefficient (P1D = 50) and a moderate vernalization requirement (P1V = 30).The positive effects of higher values of coefficient for grain filling (P5) on yield decrease when temperature increases. Anthesis and maturity are anticipated with about one week for each 1°C increase of temperature. Winter wheat cultivars with very low requirements both for vernalization and photoperiod are not suitable for South-Eastern Romania due the low yield level and very poor yield stability. Cultivars with very high requirements for photoperiod (P1D = 100) have a considerable risk for relatively low yields.

Key words: winter wheat, phenology, vernalization, photoperiod, temperature, climate change, DSSAT, simulation, South-Eastern Romania.

INTRODUCTION

Most of the modern crop simulations models require cultivar dependent coefficients controlling the differentiated response of the genotype to environmental and agro-technological conditions. The early perception of these coefficients as „genes - analogues” (Whistler et al., 1986) was enhanced by the development of the gene-based models (Hoogenboom et al., 2004).

Testing different possible values for these cultivar dependent coefficients in simulating the impact of various environment conditions approximate a trial with near isogenic lines, permitting the identification of the most appropriate values. This approach became quite widespread after it was applied in cotton with the GOSSYM model (Landivar et al., 1983a and 1983b).

For the Romanian plain, the vernalization and day-length requirements for winter wheat were for the first time estimated by Săulescu and Jinga in 1990. Used model was CERES Wheat, version 2.10 and the weather data set covered 15 years. A similar approach was used in this paper to estimate the impact of a rise in temperature with one or two Celsius degrees.

MATERIAL AND METHODS

Weather data from 1990-2008 years for the CGMS (Crop Growth Monitoring System) grid cell 47085 (50 x 50 km) was obtained from the site www.marsop.info of the AGRI4CAST Unit (ex MARS) of Institute for Protection and Security of the Citizen from the Joint Research Centre (JRC - Ispra) of European Commission.

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A description of the CGMS meteorological (including interpolation procedure) and the model infrastructure may be found in Micale and Genovese (2004) and in Lazăr and Genovese (2004). The data from the MARS database were previously used in other climate change studies (Genovese et al., 2004). The centre of the used grid cell 47085 (50 x 50 km) is located at 45°N latitude and 27°E longitude. In this paper these data will be referred as „observed data” or „scenario T + 0 °C”.

Simulations for winter wheat growth were performed with DSSAT v.4.0.2.0 (Hoogenboom et al., 2003). The sowing date was 10th of October. The soil was a cambic chernozem considered representative for the studied area.

For this study three genetic coefficients (P1V, P1D and P5) related with the winter wheat phenology were considered.

P1V specify the days at optimum vernalizing temperature required to complete vernalization. Five values (5, 15, 30, 45 and 60) were tested for this coefficient.

P1D is photoperiod sensitivity coefficient (% reduction/h near threshold). Four values were tested for this coefficient (25, 50, 75 and 100).

P5 - describing the grain filling (excluding lag) phase duration (°C.d). Three values were tested for this coefficient (400, 500 and 600).

The rest of the cultivar dependent coefficients controlling growth and phyllochrone value were kept unchanged (G1 = 25, G2 = 40, G3 = 1.5 and PHINT = 80).

So, a number of 60 cultivar dependent coefficients were tested in three temperature scenarios, each scenario consisting in 18 agricultural years.

The used weather scenarios were:

- Observed weather conditions (Scenario T + 0°C);
- Observed weather conditions ,but the temperatures values were risen by one Celsius degree (Scenario T + 1°C);
- Observed weather conditions, but the temperatures values were risen by two Celsius degrees (Scenario T + 2°C);

The rest of the weather data remained unchanged in all scenarios. Precipitation received during vegetation period (averages per year for all tested cultivars) ranged from 160 mm in 1993 to 1344 mm in 2006 (Figure 1).

The days of anthesis and maturity as well as the yield were picked up from the simulation output (Summary.out file) for each combination. Besides the averages and standard deviation for each tested „cultivar” x scenario combination, the presence percentage below the first quartile and above the third quartile was calculated. Their difference was used as an indicator for high yield stability.

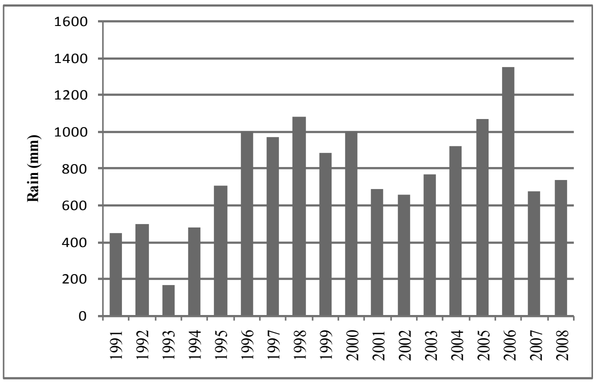

Figure 1. Precipitation during wheat vegetation period

The presence percentages were obtained by multiplying with 100 the number of years in which the cultivar was above the third quartile or respectively below first quartile and dividing the product by the total number of years.

RESULTS AND DISCUSSION

No significant correlation between simulated yield and anthesis or maturity day or grain filling duration was observed when all the individual simulations were used in any of the three scenarios. The situation was not changed by the splitting the data according the coefficient P5 (Figure 2).

The amplitude of differences in anthesis day induced by the P1V x P1D combinations was about 40 days (Figure 3). As expected the P5, controlling the grain filling duration had no influence on anthesis day.

The average anthesis day for the observed weather data (scenario T + 0°C) was 15th of May. An increase of one Celsius degree in daily temperature will result in an earlier anthesis with 7 days. For the last scenario, anthesis is anticipated with 13 days (Figure 4).

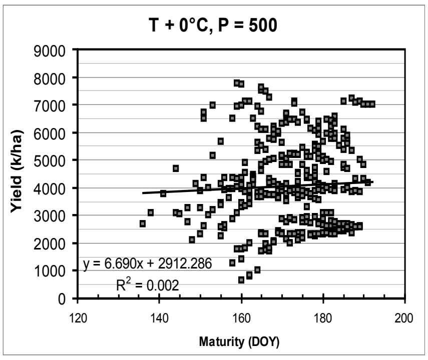

Figure 2. Scatter plot between maturity day (day of the year) and yield (kg/ha) for the cultivars with P5 = 500 for the observed weather data (Scenario T + 0°C)

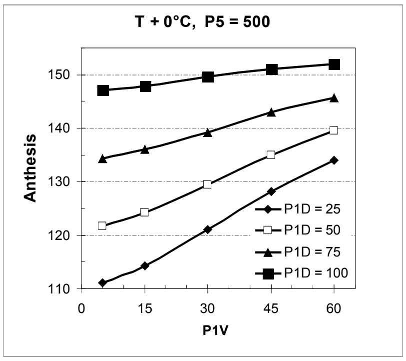

Figure 3. Influence of vernalization (P1V) and photoperiod (P1D) coefficients on anthesis day (day of the year)

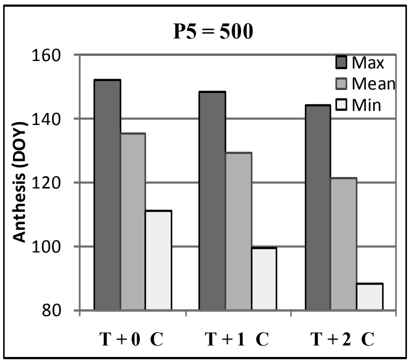

Figure 4. Changes of the maximum, average and minimum anthesis day for the three tested scenarios

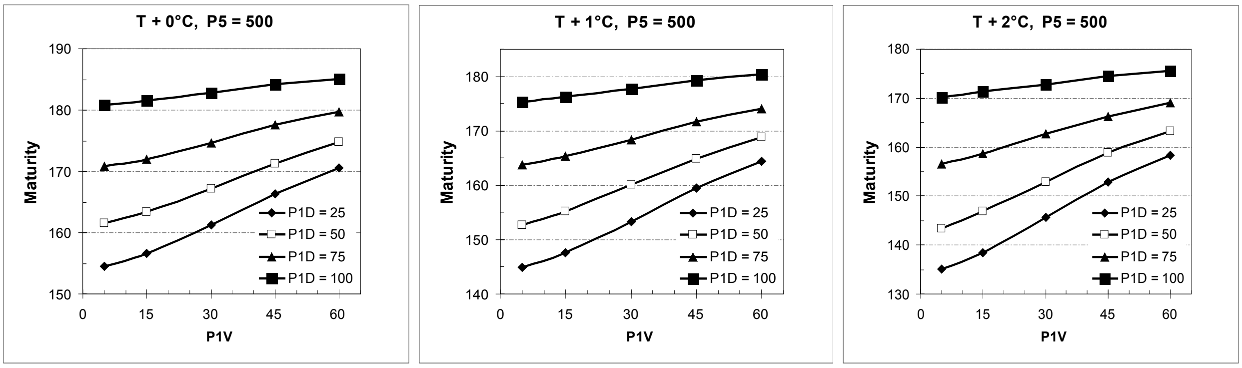

Figure 5. Influence of vernalization (P1V) and photoperiod (P1D) coefficients on maturity day (day of the year)

As expected, the coefficients of vernalization (P1V) and photoperiod (P1D) with lower values reduced the vegetation period (Figure 5). The maturity days (average for all the P1V x P1D combinations) under observed weather conditions and P5 equal with 400, 500 or 600 were 16, 20 and, respective, 25 June.

Although, the P5 values influenced the occurrence of maturity (day of the year) in observed weather conditions, they showed only an insignificant influence in the absolute reduction of the number of days required for achievement of maturity under the two scenarios with increased temperatures. Similar reductions (of 7 and 13 days) with those reported for timing of anthesis were also noticed for maturity. Increased temperatures with one and two Celsius degrees induced anticipations of latest maturity with about 5 and respective 10 days and under the same scenarios the earliest genotype anticipated maturity with 10 and respective 19 days (Figure 6).

The increase of the average yield for the twenty P1V x P1D combinations in each P5 group with temperature was not significant.

A larger increase was noticed for maximum values obtained in each scenario.

Meanwhile, the minimum yield decreased with more than 500 kg/ha as a result of increase of temperature with two Celsius degrees (Figure 7).

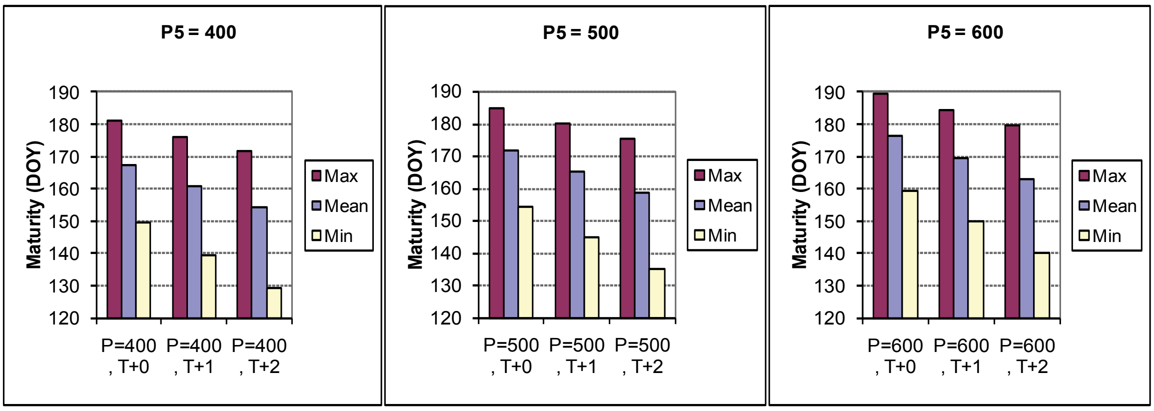

Figure 6. Changes of the maximum, average and minimum maturity day for the three tested scenarios in the cases of P5 = 400 (left chart), P5 = 500 (middle chart) and P5 = 600 (right chart)

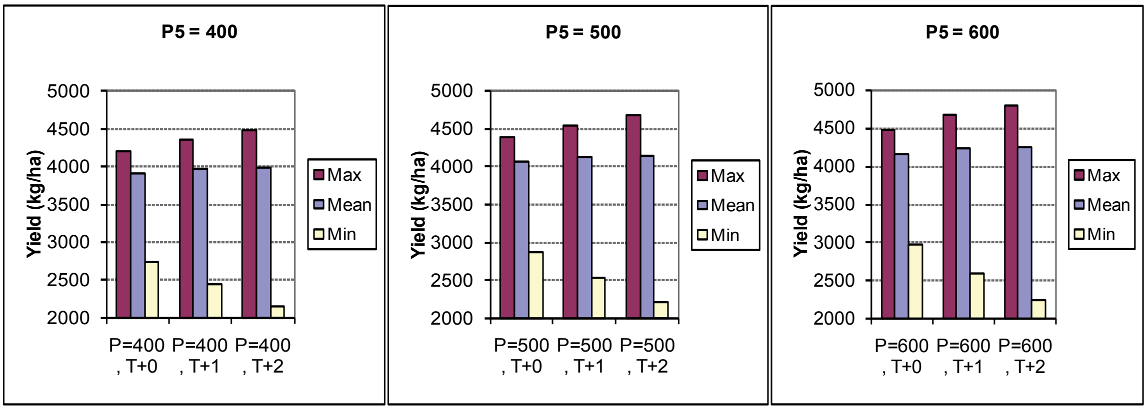

Figure 7. Changes of the maximum, average and minimum yield for the three tested scenarios in the cases of P5 = 400 (left chart), P5 = 500 (middle chart) and P5 = 600 (right chart)

Analysis of the influence of vernalization (P1V) and photoperiod (P1D) coefficients on average yield suggest that the combinations of P1D = 25 and P1V equal or less than 30 and combinations of P1D = 50 and P1V equal or less than 15 should be avoided due to lower yields in all scenarios and P5 groups (Figure 8). The genotypes with very high requirements for photoperiod (P1D = 100) failed to produce top yields in all tested combinations but they gave better yield than the five combinations mentioned above.

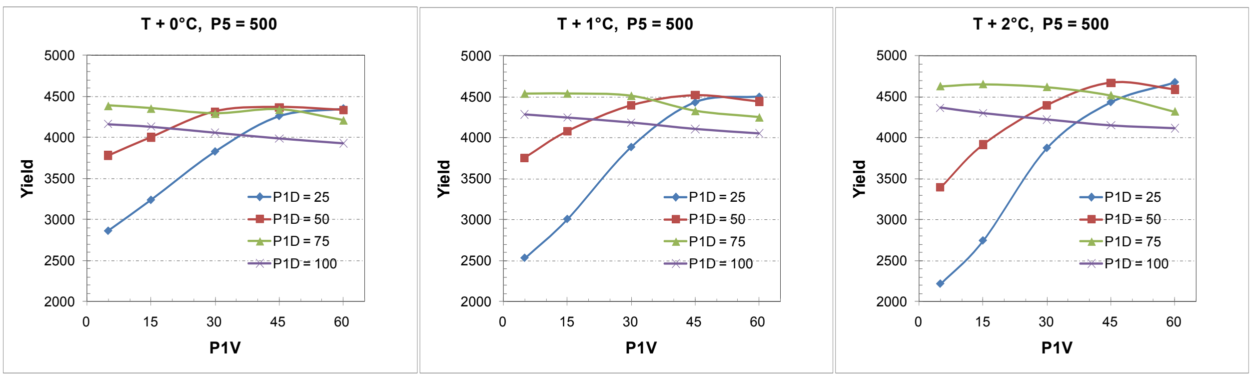

Figure 8. Influence of vernalization (P1V) and photoperiod (P1D) coefficients on average yield (1991-2008) for P5 = 500 and three thermal scenarios

Stability of high yields is one of the main breeding objectives, and a previous study for winter wheat cultivars used in South Romania pointed out that high yielding cultivars can differ significantly in yield stability (Mustățea et al., 2009). Our preference for estimating the yield stability was based on the difference between the presence percentage in the upper quartile (Table 1) and the presence percentage in the lower quartile (Table 2). This difference promote the cultivars with a stable high yield (best possible value is + 100%), although the years with an average performance are not bringing a penalty for the respective cultivar, but its presence among the worst 25% cultivars in a certain year will decrease its rank in the high – yield stability list. The values for high yield stability are shown in (Table 3) and the yield averages for 1991-2008 are presented in (Table 5). The comparison of the two tables indicates that highest yields were not always associated with the highest stability. For the scenario with observed weather data the cultivar with maximum yield was the second in stability. A stability cost (calculated as difference between yield of the stable cultivar and the maximum yield) was used to appreciate the gain in stability (calculated as difference between the chosen cultivar and the stability of the cultivar with maximum yield) (Table 4). The stability cost for the most stable cultivar was rather low (-132 kg/ha for the case of P5 = 400, -128 kg/ha for P5 = 500, and -28 kg/ha for P5 = 600) and the stability gain was 5.6% for each of the P5 groups. For the scenario „T+1°C”, the cultivar with maximum average yield was not placed in the three top positions for stability.

For this second scenario, the stability cost ranged from -94 kg/ha to -169 kg/ha and the stability gain was 22.2% for each of the P5 groups. Within the third scenario („T + 2 °C”), for the „P5 = 400” group the stability gain was 0 due to the fact that the genotype with the highest yield also achieved the maximum stability (50%). For the „P5 = 500” and „P5 = 600” groups, the stability costs were -276 kg/ha and respective -235 kg/ha, in both cases the stability gain was 16.7%. In this last scenario for these two P5 groups, a possible trade-off is to select the cultivars in the second position in stability top, due to low costs of stability (-19 to -45 kg/ha) and a stability gain of 11.1%.

Table 1. Presence percentage in the lower quartile (Risk for relatively low yields)

P5	P1V \ P1D	Scenario: T + 0 ºC				Scenario: T + 1 ºC				Scenario: T + 2 ºC			
		25	50	75	100	25	50	75	100	25	50	75	100
P5 = 400	5	72.2	50.0	5.6	22.2	88.9	55.6	0.0	11.1	94.4	72.2	0.0	11.1
	15	72.2	38.9	16.7	22.2	77.8	38.9	5.6	16.7	83.3	55.6	5.6	22.2
	30	44.4	5.6	11.1	27.8	44.4	0.0	0.0	33.3	44.4	0.0	0.0	22.2
	45	0.0	5.6	5.6	33.3	0.0	0.0	11.1	50.0	5.6	0.0	5.6	27.8
	60	5.6	5.6	11.1	44.4	0.0	5.6	22.2	38.9	0.0	0.0	0.0	50.0
P5 = 500	5	72.2	44.4	0.0	33.3	88.9	55.6	5.6	11.1	94.4	72.2	0.0	0.0
	15	66.7	38.9	5.6	27.8	83.3	38.9	0.0	11.1	83.3	50.0	0.0	16.7
	30	44.4	0.0	0.0	44.4	38.9	0.0	0.0	27.8	50.0	0.0	0.0	16.7
	45	5.6	5.6	0.0	44.4	0.0	0.0	0.0	50.0	0.0	0.0	0.0	38.9
	60	5.6	5.6	5.6	50.0	0.0	0.0	22.2	61.1	0.0	5.6	11.1	55.6
P5 = 600	5	72.2	44.4	0.0	33.3	88.9	55.6	5.6	0.0	94.4	66.7	0.0	5.6
	15	66.7	38.9	0.0	33.3	83.3	33.3	0.0	22.2	83.3	44.4	0.0	16.7
	30	44.4	0.0	0.0	44.4	33.3	5.6	0.0	33.3	44.4	0.0	5.6	16.7
	45	0.0	0.0	5.6	44.4	5.6	5.6	0.0	55.6	0.0	0.0	5.6	44.4
	60	0.0	5.6	11.1	55.6	0.0	0.0	11.1	61.1	0.0	5.6	11.1	55.6

Table 2. Presence percentage in the upper quartile (Chances for relatively good yields)

P1V \ P1D		Scenario: T + 0 ºC				Scenario: T + 1 ºC				Scenario: T + 2 ºC			
		25	50	75	100	25	50	75	100	25	50	75	100
P5 = 400	5	16.7	22.2	27.8	33.3	5.6	16.7	33.3	22.2	5.6	16.7	50.0	22.2
	15	16.7	33.3	27.8	27.8	11.1	27.8	33.3	27.8	5.6	33.3	38.9	22.2
	30	33.3	27.8	33.3	22.2	16.7	44.4	16.7	22.2	33.3	33.3	11.1	16.7
	45	33.3	33.3	16.7	16.7	50.0	27.8	16.7	16.7	38.9	44.4	16.7	16.7
	60	22.2	22.2	22.2	11.1	27.8	16.7	33.3	27.8	50.0	16.7	22.2	5.6
P5 = 500	5	16.7	22.2	27.8	22.2	5.6	22.2	44.4	22.2	5.6	16.7	44.4	22.2
	15	22.2	27.8	27.8	22.2	11.1	27.8	33.3	27.8	5.6	27.8	33.3	22.2
	30	33.3	22.2	22.2	27.8	16.7	44.4	16.7	27.8	33.3	50.0	16.7	16.7
	45	38.9	33.3	27.8	16.7	55.6	38.9	16.7	11.1	38.9	44.4	16.7	16.7
	60	27.8	27.8	16.7	11.1	16.7	11.1	33.3	16.7	33.3	27.8	16.7	5.6
P5 = 600	5	22.2	22.2	33.3	27.8	5.6	27.8	38.9	33.3	5.6	16.7	44.4	27.8
	15	22.2	33.3	16.7	22.2	11.1	33.3	27.8	27.8	5.6	27.8	33.3	22.2
	30	27.8	27.8	22.2	27.8	22.2	44.4	5.6	16.7	33.3	50.0	27.8	22.2
	45	38.9	22.2	22.2	27.8	55.6	44.4	16.7	16.7	44.4	27.8	22.2	11.1
	60	22.2	33.3	11.1	11.1	22.2	11.1	16.7	16.7	27.8	16.7	22.2	11.1

Table 3. Yield stability as a difference between the presence percentage in the upper quartile and the presence percentage in the lower quartile

P1V \ P1D		Scenario: T + 0 ºC				Scenario: T + 1 ºC				Scenario: T + 2 ºC			
		25	50	75	100	25	50	75	100	25	50	75	100
P5 = 400	5	-55.6	-27.8	22.2	11.1	-83.3	-38.9	33.3	11.1	-88.9	-55.6	**50.0**	11.1
	15	-55.6	-5.6	11.1	5.6	-66.7	-11.1	27.8	11.1	-77.8	-22.2	33.3	0.0
	30	-11.1	22.2	22.2	-5.6	-27.8	**44.4**	16.7	-11.1	-11.1	33.3	11.1	-5.6
	45	**33.3**	**27.8**	11.1	-16.7	**50.0**	27.8	5.6	-33.3	33.3	**44.4**	11.1	-11.1
	60	16.7	16.7	11.1	-33.3	27.8	11.1	11.1	-11.1	**50.0**	16.7	22.2	-44.4
P5 = 500	5	-55.6	-22.2	**27.8**	-11.1	-83.3	-33.3	38.9	11.1	-88.9	-55.6	**44.4**	22.2
	15	-44.4	-11.1	22.2	-5.6	-72.2	-11.1	33.3	16.7	-77.8	-22.2	33.3	5.6
	30	-11.1	22.2	22.2	-16.7	-22.2	**44.4**	16.7	0.0	-16.7	**50.0**	16.7	0.0
	45	**33.3**	**27.8**	**27.8**	-27.8	**55.6**	38.9	16.7	-38.9	38.9	44.4	16.7	-22.2
	60	22.2	22.2	11.1	-38.9	16.7	11.1	11.1	-44.4	33.3	22.2	5.6	-50.0
P5 = 600	5	-50.0	-22.2	33.3	-5.6	-83.3	-27.8	33.3	33.3	-88.9	-50.0	**44.4**	22.2
	15	-44.4	-5.6	16.7	-11.1	-72.2	0.0	27.8	5.6	-77.8	-16.7	33.3	5.6
	30	-16.7	27.8	22.2	-16.7	-11.1	**38.9**	5.6	-16.7	-11.1	**50.0**	22.2	5.6
	45	**38.9**	22.2	16.7	-16.7	**50.0**	38.9	16.7	-38.9	**44.4**	27.8	16.7	-33.3
	60	22.2	27.8	0.0	-44.4	22.2	11.1	5.6	-44.4	27.8	11.1	11.1	-44.4

For each P5 X scenario combinations, the bold and the underlined values are for the most stable genotype, the cells bolded but not underlined are for the second genotype in the yield stability hierarchy and the shadowed cells indicate the location of the genotype with the maximum average yield.

Table 4. Stability costs and stability gains as compared with the genotype with the maximum average yield for each P5 x scenario combinations

P5 group	Scenario T+ …	P1V	P1D	Stability cost for first place (kg/ha)	Stability cost for the second place (kg/ha)	Yield for the first place in stability classification (kg/ha)	Yield for the second place in stability classification (kg/ha)	Maximum yield (kg/ha)	Stability gain for first place as compared with stability of the genotype with maximum average yield	Percentage from the yield of the most stable cultivar from "P5 = 400" group
400	0	45	25	-132	0	4071	4202	4202	5.6	100
500	0	45	50	-128	0	4261	4390	4390	5.6	105
600	0	45	25	-28	0	4454	4482	4482	5.6	109
400	1	45	25	-94	-114	4261	4242	4355	22.2	100
500	1	45	25	-110	-147	4437	4400	4547	22.2	104
600	1	45	25	-169	-8	4520	4680	4688	22.2	106
400	2	60	25	0	-4	4480	4476	4480	0.0	100
500	2	30	50	-276	-45	4399	4631	4675	16.7	98
600	2	30	50	-235	-19	4566	4782	4801	16.7	102

Table 5. Average yield

	P1D	Scenario: T + 0 ºC				Scenario: T + 1 ºC				Scenario: T + 2 ºC			
	P1V	25	50	75	100	25	50	75	100	25	50	75	100
P5 = 400	5	2742	3620	4175	4041	2449	3587	4323	4114	2147	3266	**4447**	4200
	15	3116	3830	4142	4021	2885	3893	4354	4089	2677	3772	4475	4165
	30	3684	4098	4153	3948	3741	**4242**	4329	4034	3744	4206	4390	4081
	45	**4071**	**4202**	4142	3886	**4261**	4320	4153	3964	4227	**4476**	4358	3998
	60	4178	4181	4068	3832	4355	4275	4098	3948	**4480**	4401	4210	3978
P5 = 500	5	2866	3782	**4390**	4165	2532	3756	4546	4288	2218	3396	**4631**	4368
	15	3241	4005	4357	4134	3008	4082	4547	4250	2745	3919	4656	4301
	30	3830	4317	4295	4061	3890	**4400**	4519	4188	3874	**4399**	4621	4225
	45	**4261**	**4369**	**4344**	3990	**4437**	4523	4333	4109	4433	4673	4519	4155
	60	4353	4334	4214	3930	4506	4447	4255	4054	4675	4592	4321	4121
P5 = 600	5	2967	3887	**4482**	4269	2596	3887	4667	4396	2238	3504	**4782**	4462
	15	3321	4114	4425	4228	3132	4189	4688	4364	2813	4038	4801	4393
	30	3911	4482	4400	4164	4030	**4512**	4608	4293	3984	**4566**	4739	4320
	45	**4454**	4462	4443	4085	**4520**	**4680**	4423	4186	**4597**	4772	4635	4250
	60	4476	4417	4307	4015	4671	4539	4354	4133	4780	4718	4431	4224

For each P5 X scenario combinations, the bold and the underlined values are for the most stable genotype, the cells bolded but not underlined are for the second genotype in the yield stability hierarchy and the shadowed cells indicate the location of the genotype with the maximum average yield.

Regarding the P1V x P1D combinations that provided the best high yield stability, for the observed weather conditions from 1991-2008, the most stable combinations were given by cultivars with low sensibility for photoperiod (P1D = 25) and rather high requirement for vernalization (P1V = 45). The stability index was 33.3% for the „P5 =400” and „P5 = 500" groups, and 38.9% for the „P5 = 600" group.

This combination (P1D = 25, P1V = 45) remained the most stable even if the temperature increases with 1°C (scenario „T + 1°C") and even more the stability index increased to 50% for „P5=400" and „P5= 500" groups and in case of the group „P5 = 600" the stability index reached 55.6%. In condition of a increased temperature with 2 °C (scenario „T + 2 °C"), the simulations suggest that even if the averages yield reductions are limited at only 200 kg/ha in the case that the most stable cultivars for actual weather conditions are used in this last scenario, for obtaining a higher yield stability, new combinations P1V x P1D must be chosen. So, for the „P5 =400" group a cultivar with low sensibility for photoperiod (P1D = 25) and higher requirements for vernalization (P1V = 60) should be prepared. This cultivar provided also the maximum average yield. Another possible choice for this group may be a cultivar with rather high sensibility to photoperiod (P1D = 75) and very low requirements for vernalization (P1V = 5). This second choice may be considered as an option also for the other two P5 groups in the scenario „T + 2 °C", but for these groups the highest stability was given by the combination of P1D = 50 and P1V = 45. The choice of cultivars with low requirements for vernalization would bring however a reduction of winter hardiness, increasing the risk of winter damage. The yield of the most stable cultivar from the „P5 = 500" group under present weather conditions was 5% higher than the yield of the most stable cultivar from the „P5 = 600" group. In case of the „P5 = 600" this increase reached 9%. In the „T + 1°C" scenario, the increases brought by higher P5 coefficients were limited to 4% and respectively 6%. This influence decreased even more in the „T + 2 °C" scenario, the increase for the group „P5 = 600" was only 2% and in case of the mid values for P5 the yield of the most stable cultivar was with -2% below the yield of most stable cultivar in the „P5 = 400" group. The yield of the most stable cultivar from the „P5 = 500" group under weather conditions was 5% higher than the most stable cultivar from the „P5 = 600" group. In case of the „P5 = 600" this increase reached 9%. In the „T + 1 °C" scenario, the increases brought by higher P5 coefficients were limited at 4% and respectively 6%. This influence decreased even more in the „T + 2 °C" scenario, the increase for the group „P5 = 600" was only 2% and in case of the mid values for P5 the yield of the most stable cultivar was with -2% below the yield of most stable cultivar in the „P5 = 400" group.

Most of the cultivars with a very high sensitivity to photoperiod (P1D = 100) presented a considerable risk of relatively low yields (Table 1). Under the current weather conditions, the risk for relatively low yield was 37.4% (average of all cultivars). Increase of temperature decrease somehow this risk (to 32.2% for the „T + 1 °C" scenario), but it remained a limitation for these cultivars even in the conditions of „T + 2 °C" scenario where the average risk for a low yield was 26.7%

This study was self-limited to the arbitrary scenarios related with temperature and it was not intended to cover the complex determinism of yield under a foreseen climate change scenario: changes in monthly averages and frequency of extreme events for all weather factors, changes in cultural practices, new pest and diseases patterns etc. A follow-up study regarding the interactions with possible alterations of the rain pattern is necessary.

CONCLUSIONS

Winter wheat cultivars with very low requirements both for vernalization and photoperiod are not suitable for South-Eastern Romania due the low yield level and very poor yield stability. Cultivars with very high requirements for photoperiod (P1D = 100) have a considerable risk of relatively low yields.

Increases of temperatures with 1 or 2°C are not expected to have a negative impact on the long term average yield but the differences between years will increase and the penalties for the non-adapted cultivars will be higher.

For the current weather conditions of South-Eastern Romania, the cultivars with low sensibility for photoperiod (P1D = 25) and rather high requirement for vernalization

(P1V = 45) have the best stability for high yields for all three tested values (400, 500 and 600) for the P5 coefficient (controlling the grain fill duration).

If temperature increases with 1°C, the yield stability of these ideotypes is expected to increase significantly, but for an increase with 2°C, an increase of vernalization requirements is suggested for the cultivars with shorter grain filling period (P1D = 25, P1V = 60, P5 = 400) and for cultivars with mid and longer grain filling period a high yield stability was given by a low to moderate value for photoperiod coefficient (P1D = 50) and a moderate vernalization requirement (P1V = 30).

The positive effects of higher values of the coefficient for grain filling (P5) on yield are expected to decrease when temperature increases.

Anthesis and maturity are anticipated with about one week for each 1°C increase of temperature.

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