PERFORMANCE OF SEVERAL WHEAT CULTIVARS UNDER CONTRASTING CONDITIONS OF WATER STRESS, IN CENTRAL PART OF OLTENIA

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ABSTRACT

Seventy six wheat cultivars of different origin were compared in yield trials at ARDS Şimnic during 2005-2007, and data from two contrasting years, 2005 - with high rainfall and 2007 - with drought conditions were used to calculate several stress response indices and to analyze the cultivar response to drought. Yields in the normal year were not correlated with yields in the stress year, but several cultivars with good performance under both conditions were identified. Best performers under both stress (yields over 3 tons/ha) and non-stress conditions (yields over 6 tons/ha) were Romanian cultivars Alex, Glosa, Romulus and Crina, and the introduced cultivar Orion. Better stress susceptibility index (SSI) and stress tolerance index (TOL) was associated with low yield under normal conditions, and therefore these indices could not identify cultivars with good performance in both stress and non-stress years. Stress tolerance index (STI) gave identical cultivar classification with the geometric mean (GMP), both being better than SSI or TOL in identifying top yielders in contrasting water availability conditions. However, they were not better than the arithmetic average yield. A simple practical way to select for best performance in contrasting conditions is the analysis of the two-way distribution of cultivars, according to their yield in the respective conditions.

Key words: wheat, water stress, stress susceptibility index, stress tolerance index.

INTRODUCTION

Drought resistance is defined as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. The ability of wheat cultivars to perform reasonably well in variable rainfall and water stressed environments is an important trait for stability of production under drought stress conditions (Pirayvatlou, 2001).

Water stress is very heterogeneous, both in time (among seasons and years) and space (among and within locations) and highly unpredictable, and this reduces the efficiency of selection for resistance to this stress.

Drought resistance has long been one of the high priority breeding objectives in Romania, and several cultivars and promising lines with improved performance under water stress have been identified (Săulescu et al., 1998; Mustăţea et al., 2003).

Several drought stress indices or selection criteria, such as TOL = stress tolerance (Rosielle and Hamblin, 1981); MP = mean productivity; GMP = geometric mean (Ramirez and Kelly, 1998); SSI = stress susceptibility index (Fisher and Maurer, 1978); STI = stress tolerance index (Fernandez, 1992), have been proposed as ways to identify genotypes with better stress tolerance.

A larger value of TOL and SSI show relatively more sensitivity to stress, thus a smaller values of TOL and SSI are favored. Several authors noticed that selection based on these two indexes favors genotypes with low yield under non-stress conditions and high yield under stress conditions (Golabadi et al., 2006). To reduce the disadvantage due to the significant correlation between SSI and yield under non-stress, Săulescu et al. (1998) suggested the use of deviations from the linear regression of SSI on yield in favorable conditions.

Fernandez (1992) claimed that selection based on STI and GMP would result in genotypes with higher stress tolerance and good yield potential.

Our study is an attempt to compare the usefulness of several drought stress indices for identification of cultivars with better performance at different levels of water stress.

MATERIAL AND METHODS

Seventy six wheat cultivars of various origins were studied in field experiments during three years (2005-2007) at Şimnic Agricultural Research & Development Station, which is situated in an area known for frequent rainfall deficits and high summer temperatures. Out of these years, 2005 was favorable for wheat year (total rainfall during the vegetation period 709 mm) and 2007 was a dry year (total rainfall during the vegetation period 305.5 mm, with 55 days from March to May without any rain and higher than normal temperatures). The multi-annual average at Şimnic is 456.9 mm.

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We used the yield data of these two years to calculate for each cultivar:

TOL - the yield difference between the stress (Ys) and non-stress conditions (Yp);

MP - the average yield of Ys and Yp;

GMP – calculated with formula $\sqrt{Ys.Yp}$;

SSI – stress susceptibility index expressed by following relationships:

SSI = [1-Ys/Yp]/SI, where SI (stress intensity) and is estimated as $\left[1-\left(\frac{\overline{Ys}}{\overline{Yp}}\right)\right]$

where:

$\overline{Ys}$ = mean yield over all genotypes evaluated under stress conditions;

$\overline{Yp}$ = mean yield over all genotypes evaluated under non-stress conditions.

STI = stress tolerance index $\left[\mathrm{Yp.Ys}/\ \overline{\mathrm{Yp}^2}\right]$

Cultivars were grouped according to their origin and all indices were calculated separately for each group of wheat cultivars.

RESULTS

The stress intensity, calculated from the average yield under stress and average yield of the favorable year was 0.53, reflecting the fact that on average, yield in 2007 was about half of the yield in 2005.

Romanian cultivars, which were the largest group of tested material, had yields from 4050 kg/ha (in cultivar Albota) and 6960 kg/ha (in cultivar Alex) under the normal conditions of the year 2005, the average being 5594 kg/ha. Nine of these cultivars (41%) produced over 6000 kg/ha in 2005. Under drought conditions of the year 2007, yields varied from 2230 kg/ha (Beti) to 3500 kg/ha (Alex), with an average of 2855 kg/ha. Eight of the tested Romanian cultivars (36%) produced over 3000 kg/ha under water stress, and four out of these (18%) also had yields over 6000 kg/ha under normal conditions. From the stress tolerance point of view (TOL) lowest values were recorded in cultivars Albota, Flamura 85, Gabriela and Fundulea 4. Obviously, this index only pointed out the cultivars with lowest yield in normal conditions. Highest average yield (MP) and geometric mean yield (GMP) were recorded in cultivars Alex (MP = 5230 kg/ha and GMP = 4935 kg/ha), Glosa (MP = 5075 kg/ha and GMP = 4765 kg/ha) and Romulus (MP = 4930 kg/ha and GMP = 4605 kg/ha) (Table 1).

Table 1. Stress tolerance attributes in Romanian wheat cultivars, estimated from yields obtained in a normal year (2005) and a dry year (2007) at ARDS Şimnic

Cultivar	Yp	Ys	TOL	MP	GMP	SSI	STI
Boema	5500	3420	2080	4460	4337	0.71	0.658
Romulus	6690	3170	3520	4930	4605	0.99	0.743
Delabrad	5730	3000	2730	4365	4146	0.90	0.602
Glosa	6820	3330	3190	5075	4765	0.98	0.795
Fl 85	4700	2930	1710	3815	3711	0.71	0.482
Crina	6130	3140	2990	4635	4387	0.92	0.674
Izvor	4490	2860	1630	3675	3583	0.72	0.450
Dropia	5440	2740	2700	4090	3861	0.94	0.522
Gruia	5670	3100	2570	4385	4192	0.86	0.615
Ş 30	6560	2650	3910	4605	4169	1.12	0.609
Alex	6960	3500	3460	5230	4935	0.94	0.853
F4	4420	2610	1810	3515	3396	0.77	0.404
Rapid	6420	2940	3480	4680	4345	1.02	0.661
Faur	6000	2510	3490	4255	4070	1.10	0.527
Lv 34	5550	2490	3060	4020	3717	1.04	0.484
Dor	6820	2650	4170	4735	4251	1.15	0.633
Briana	5310	2510	2800	3910	3651	0.99	0.467
Albota	4050	3300	750	3675	3656	0.35	0.468
Beti	4140	2230	1910	3185	3038	0.87	0.323
Gabriela	4560	2830	1730	3695	3592	0.72	0.452
Gas-parom	4600	2430	2170	3515	3378	0.89	0.391
Trivale	6510	2480	4030	4495	4018	1.17	0.565
Mean	*5594*	*2855*	*2739*	*4225*	*3996*	*0.897*	*0.560*

On average, Romanian cultivars recorded a GMP value of 3996 kg/ha. Simultaneous use of SSI values and higher Yp values pointed out Romulus, Glosa, Crina and Alex cultivars. Average value of SSI in Romanian cultivars was lower than 1 (0.879) indicating drought stress tolerance. According to STI value, Alex, Glosa and Romulus cultivars were in the first group followed by Boema, Delabrad, Crina, Gruia, Şimnic 30, Rapid and Dor with STI higher than 0.600. The average STI in Romanian cultivars was 0.560, the highest value in this experiment, indicating that they are the most tolerant to drought conditions. These results were obtained despite the fact that the group of Romanian cultivars included many cultivars bred for different climatic conditions by the breeding centers of Suceava, Podu-

Iloaiei and Albota, and not adapted to the environment of Şimnic.

Tested Hungarian cultivars yielded under normal conditions from 4042 kg/ha (GK Othalom) and 5880 kg/ha (Mariska), the average yield being 14% lower than Romanian cultivars average. Under stress conditions the yield varied from 1590 kg/ha (GK Elet) to 3380 kg/ha (Martina), the average being also 14% lower than the average of Romanian cultivars. None of the cultivars yielded over 6000 kg/ha in 2005 and only one (9%) produced over 3000 kg/ha in 2007. Both MP and GMP show the best values in cultivars Martina, Serina and Mariska (Table 2).

Table 2. Stress tolerance attributes in Hungarian wheat cultivars, estimated from yields obtained in a normal year (2005) and a dry year (2007) at ARDS Şimnic

Cultivar	Yp	Ys	TOL	MP	GMP	SSI	STI
Martina	5730	3380	2350	4555	4401	0.77	0.678
Serina	5710	2850	2860	4280	4034	0.95	0.570
Mariska	5880	2750	3130	4315	4021	1.00	0.566
GK Pinka	4190	2620	1570	3405	3313	0.71	0.384
Mv Emese	4170	2240	1930	3205	3056	0.87	0.327
Mv Mambo	4130	2190	1940	3160	3007	0.89	0.317
Madrigal	4940	2570	2370	3755	3563	0.91	0.445
GK elet	4960	1590	3370	3275	2808	1.28	0.276
GK Miska	5071	2290	2781	3681	3407	1.03	0.407
GK Petur	4243	1870	2373	3057	2817	1.06	0.278
GK Othalom	4042	2756	1286	3398	3338	0.60	0.390
Mean	*4824*	*2464*	*2360*	*3644*	*3433*	*0.915*	*0.422*

Average yield of Austrian and German cultivars under favorable conditions was practically equal with the average yield of Romanian cultivars, while under stress conditions the average yield of these cultivars was 7% lower than the average yield of Romanian cultivars. Three cultivars (33%) produced over 6000 kg/ha in 2005. Cultivars Exotic and Cubus had the highest yields in 2005 (7470 kg/ha and 7040 kg/ha respectively), but they yielded under 3000 kg/ha in the dry year 2007. Only Carolina produced over 3000 kg/ha under the stress conditions of 2007, but its yield under normal conditions was below average.

Average MP and GMP as well as average STI of this group were close to those of Romanian cultivars, but individually no cultivar combined good performance under normal and stress conditions (Table 3).

Table 3. Stress tolerance attributes in Austrian and German wheat cultivars, estimated from yields obtained in a normal year (2005) and a dry year (2007) at ARDS Şimnic

Cultivar	Yp	Ys	TOL	MP	GMP	SSI	STI
Carolina	5322	3130	2192	4226	4081	0.77	0.583
Exotic	7470	2840	4630	5155	4606	1.17	0.743
Dunai	5220	2780	2440	4000	3809	0.90	0.508
Meunier	6050	2660	3390	4355	4012	1.06	0.564
Josef	4580	2660	1920	3620	3490	0.79	0.427
Cordiale	5970	2540	3430	4255	3894	1.08	0.531
Cubus	7040	2520	4520	4780	4212	1.21	0.621
Fridoline	4920	2420	2500	3670	3450	0.96	0.417
Capo	4523	2340	2183	3432	3253	0.91	0.371
Mean	*5677*	*2654*	*3013*	*4166*	*3867*	*0.98*	*0.529*

Even if average yield under normal conditions in cultivars from the former USSR was very close to the average of Romanian cultivars, their average yield under stress was 30% below Romanian cultivars. Five cultivars (45%) had yields over 6000 kg/ha in 2005 but no cultivar of this group had yields higher than 3000 kg/ha under stress, GMP higher than 4000 kg/ha or STI higher than 0.600. With the exception of Bezostaya 1, SSI values were higher than 1.00, suggesting that they are not adapted for this area (Table 4).

Although known for their high yielding potential, French cultivars yielded on average 6% less than Romanian cultivars, and all French cultivars yielded less than 6000 kg/ha in the normal year 2005. Probably they were more affected by other stresses, present even in a year considered as favorable. In the dry year 2007, average yield was almost equal to the average of Romanian cultivars and two cultivars (33%) produced more than 3000 kg/ha.

Table 4. Stress tolerance attributes in Russian and Ukrainian wheat cultivars, estimated from yields obtained in a normal year (2005) and a dry year (2007) at ARDS Şimnic

Cultivar	Yp	Ys	TOL	MP	GMP	SSI	STI
Bezostaya 1	5040	2680	2360	3860	3675	0.88	0.473
Kjajna	5430	1520	3910	3475	2873	1.36	0.289
Khvylia	5430	2340	3090	3885	3565	1.07	0.445
Koska	6100	2480	3620	4290	3889	1.11	0.530
Demetra	6450	1250	5200	3850	2839	1.52	0.282
Mironovsk	6470	1880	4590	4175	3488	1.34	0.426
Ofelia	4110	1780	2330	2945	2705	1.07	0.256
Krasnodar	6110	1970	4140	4040	3469	1.29	0.422
Lada	4950	1860	3090	3405	3034	1.17	0.322
Preloma	5190	2340	2850	3765	3485	1.04	0.425
Vesta	6820	1810	5010	4315	3513	1.39	0.432
Mean	*5645*	*1992*	*3653*	*3819*	*3353*	*1.20*	*0.391*

Based on GMP and STI values in this group, the cultivar Aztec could be considered relatively drought tolerant (Table 5).

Table 5. Stress tolerance attributes in French wheat cultivars, estimated from yields obtained in a normal year (2005) and a dry year (2007) at ARDS Şimnic

Cultivar	Yp	Ys	TOL	MP	GMP	SSI	STI
Aztec	5930	3370	2570	4650	4470	0.81	0.700
Cezanne	5430	3010	2420	4220	4043	0.84	0.572
Bercy	5530	2870	2660	4200	3984	0.91	0.556
Enesco	4650	2830	1820	3740	3628	0.74	0.461
Apache	5630	2670	2960	4150	3877	0.99	0.526
Renan	4320	2170	2150	3245	3062	0.94	0.328
Mean	*5248*	*2820*	*2428*	*4034*	*3847*	*0.872*	*0.524*

Cultivars originating from Israel had low yields both in 2005 and 2007 and are obviously not suitable for planting in the conditions of Oltenia (Table 6).

Table 6. Stress tolerance attributes in Israeli wheat cultivars, estimated from yields obtained in a normal year (2005) and a dry year (2007) at ARDS Şimnic

Cultivar	Yp	Ys	TOL	MP	GMP	SSI	STI
Hazera 307	3700	1790	1910	2745	2574	0.97	0.232
Bhash	3890	1800	2090	2845	2646	1.01	0.245
Shoham	5440	2520	2920	3980	3703	1.01	0.480
Dariel	3460	1910	1550	4675	2571	0.85	0.231
Mean	*4123*	*2005*	*2118*	*3064*	*2875*	*0.96*	*0.297*

Several wheat cultivars of various origins were analyzed as the last group. Two cultivars inside of this group showed very good indices: Orion (GMP = 4801 kg/ha, SSI = 0.780, STI = 0.807) and Frini (GMP = 4151 kg/ha, SSI = 0.750, STI = 0.603) (Table 7). Both had yields over 3000 kg/ha under stress, but only Orion also had good yield in 2005. In the case of Frini the good values of SSI and SI are clearly due to the low yield in the normal year.

Table 7. Stress tolerance attributes in several wheat cultivars of various origins, estimated from yields obtained in a normal year (2005) and a dry year (2007) at ARDS Şimnic

Cultivar	Yp	Ys	TOL	MP	GMP	SSI	STI
Orion	6280	3670	2610	4975	4801	0.78	0.807
Frini	5350	3220	2130	4285	4151	0.75	0.603
Kristina	4690	1500	3190	3095	2652	1.28	0.246
Defence	5260	2680	2580	3970	3755	0.93	0.494
Solomon	5230	1660	3570	3445	2946	1.29	0.304
Albatros	6370	1900	4470	4135	3479	1.32	0.424
Rowhide	5010	2010	3000	3510	3173	1.13	0.353
Vorona	5210	1940	3270	3575	3179	1.18	0.354
Georgia 1	4150	2010	2140	3080	2888	0.97	0.292
Hoff	4990	2040	2950	3515	3191	1.11	0.357
Columna	4400	1710	2690	3055	2773	1.15	0.264
Patton	6910	1200	5710	4055	2880	1.56	0.290
Mean	*5321*	*2128*	*3193*	*3725*	*3365*	*1.12*	*0.398*

DISCUSSION

Results of this study, which are based on only two-year yield data, should be regarded with caution. Stresses, other than water stress, could have differentially affected yield in the „normal" year, while performance under stress could reflect stress intensity and timing, specific to the year 2007. On the other hand, results in other years can be strongly influenced by differential cultivar sensibility or tolerance to other stresses like freezing winter temperatures, heat during grain filling, lodging, and various diseases, which were not present in the two years of study. For these reasons, any recommendation based on this study, about best cultivars to be grown in the region, could only be considered very preliminary.

An analysis of correlations between the various stress tolerance parameters used in this

study provides interesting observations about the information reflected by each of them (Table 8).

Table 8. Correlation between several stress tolerance parameters

	Yp	Ys	TOL	MP	GMP	SSI
Yp	1					
Ys	0.24	1				
TOL	**0.82**	**-0.36**	1			
MP	**0.81**	**0.62**	**0.41**	1		
GMP	**0.69**	**0.87**	0.15	**0.88**	1	
SSI	**0.48**	**-0.72**	**0.88**	0.004	-0.28	1
STI	**0.69**	**0.86**	0.15	**0.88**	**0.99**	-0.27

Correlation coefficients written in bold are significant at P<0.01

Yields in the normal year (Yp) were not correlated with yields in the stress year (Ys) (r = 0.24 n.s.).

Stress tolerance (TOL) was strongly correlated with yield in non-stress conditions and negatively correlated with yield under stress. Having in mind the fact that a small value of TOL is desirable, selection for this parameter would tend to favor low yielding genotypes.

As expected, mean productivity (MP) and geometric mean productivity (GMP) were strongly correlated with both Yp and Ys, MP being slightly more influenced by the „normal" yield and GMP more influenced by the stress yield. Therefore, despite the strong correlation between GMP and MP (r = 0.88), GMP can be considered to reflect a little better the performance under stress than MP.

The stress susceptibility index (SSI) introduced by Fisher and Maurer (1978) was strongly negatively correlated with yield under stress and presented a weaker positive correlation with yield in normal conditions. Having in mind the fact that a small value of SSI is desirable, selection for this parameter would also tend to favor low yielding genotypes, but to a much smaller extent than selection for TOL.

The stress tolerance index (STI) introduced by Fernandez (1992) was perfectly correlated with GMP, from which it is calculated, and therefore we can consider that it contains the same information. Like GMP it is correlated with both Yp and Ys, the correlation with yield under stress being slightly better (0.86 vs. 0.69).

From the farmer's point of view, best cultivars should be top yielders both in normal and stress conditions. From the two-way distribution of cultivars according to the yield in the two contrasting years, one can identify 5 cultivars, which produced over 6000 kg/ha in 2005 and over 3000 kg/ha in 2007 (Figure 1). None of the criteria used above for describing drought response identified all these cultivars as the best. Four of these cultivars were among the top five for MP, GMP and STI, two among the top five for Yp and Ys, and none among the top five for TOL and SSI.

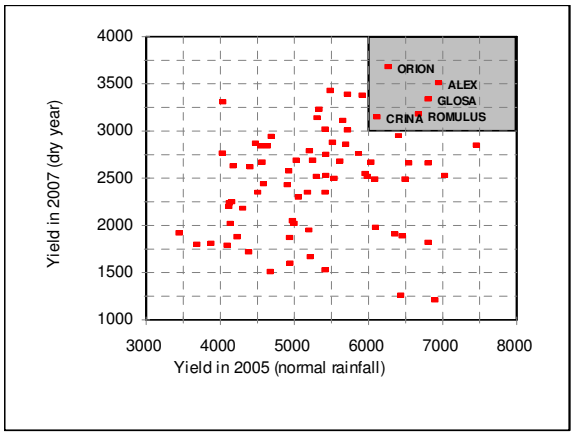

Figure 1. Two-way distribution of wheat cultivars, according to yields in 2005 and 2007

Therefore, from this point of view MP, GMP and STI seem to be more useful, but probably not better than a simple analysis of the two-way distribution according to yield in the two contrasting conditions.

CONCLUSIONS

Preliminary data from two years with contrasting water availability indicate that chances of identifying cultivars with good yields both under normal and stress conditions, in central part of Oltenia, are better among Romanian cultivars than among cultivars that were bred in other weather and soil conditions. Best performers under both stress and non-stress conditions were Romanian cultivars Alex, Glosa, Romulus and Crina, and the introduced cultivar Orion.

Yields in the normal year 2005 were not correlated with yields in the stress year 2007, and this underlines the need of extensive testing of cultivars, under various conditions.

Better stress susceptibility index (SSI) and stress tolerance index (TOL) was associated with low yield under normal conditions, and therefore these indices could not identify cultivars with good performance in both stress and non-stress years.

Stress tolerance index (STI) gave identical cultivar classification with the geometric mean (GMP), both being better than SSI or TOL in identifying top yielders in contrasting water availability conditions. However they were not better than the arithmetic average yield.

A simple practical way to select for best performance in contrasting conditions is the analysis of the two-way distribution of cultivars, according to their yield in the respective conditions.

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