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Short communication

A pot evaluation of the sensitivity of spring barley (*Hordeum vulgare* L.) to water stress applied at different growth stages

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Abstract. Two-year pot experiments with three varieties of spring barley were carried out. Water stress (water deficit of soil up to 40% of field water-holding capacity) was employed in four basic growth stages of plants: tillering, shooting (stem extension stage), ear formation and milk maturity. Reactions of the plants to water stress were expressed by a decline in the grain yield of the studied varieties throughout the growing season. The greatest losses in production of spring barley grain due to the experienced water stress of the plants were found at the beginning of ear formation and milk maturity stages of the grain. The sensitivity of the plants to the stress caused by water deficit in the soil during the initial period of their vegetative growth was smaller. Varieties showed significantly different sensitivities to the experienced water stress, depending on the growth stage during which the plants suffered from the stress.

Key words: *Hordeum vulgare*, genetic variation, drought sensitivity, growth stages.

In different regions of Poland, shorter or longer periods of water deficit in the soil occur almost in each year and stage-specific alterations in the evaporative use of water can be observed. Water shortage is known to inhibit numerous physiological, chemical and physical growth processes and to reduce evapotranspiration and photosynthetic activity of plants, which results in decreased crop production (CARLSON et al. 1980, KOWALIK 1989, VARLEV, POPOVA 1994). There are considerable genotypic differences in the tolerance of crop plants to unfavourable soil moisture (STARCK et al. 1995, GÓRNY 1999). The newly registered crop cultivars exhibit a high yield potential, but simultaneously they show a broad variability in

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water requirements (COBORU 1978-1997, MARTYNIAK 1986, MARTYNIAK et al. 1995). The response to water stress is known to change with growth stage and stress duration (GÓRECKI, GRZESIUK 1978, MORAN et al. 1994, VARLEV, POPOVA 1994).

The adverse effects of drought are more frequently noticed in spring cereals, especially during spring and early summer. At that period, winter cereals have a deep root system that enables them to utilize water from deeper soil layers. Therefore, a wide knowledge of the responses to less favourable soil water status at particular growth stages seems to be of great importance for the practice. Since such information may help in yield prediction, further improvements in research methods are necessary.

Investigations were initiated at the Institute for Land Reclamation and Grassland Farming in Falenty to estimate indices of yield reduction caused by water deficits at different growth stages in recently registered cultivars of spring cereals. In this paper, results of pot examinations on barley cultivars are shortly discussed. Plant material consisted of the following three cultivars of spring barley: the German cv. Maresi (brewery type, registered in 1991), the Polish cv. Rudzik (brewery type, registered in 1987) and the Polish cv. Rataj (fodder type, registered in 1996).

Two randomized experiments were performed in 1997 (with four replications) and 1998 (with six replications) under controlled conditions of the vegetation-hall of the institute in Falenty. Plants were grown in modified Mitscherlich's pots supplied with a saucer on percolating. The pots were filled with an arable soil (pH 6.4, field water capacity 23.2 %) that originated from the A horizon of the local experimental field. To optimize the soil fertility, macronutrients were added before sowing in the following rate (mg/pot): 28 N (as NH_4NO_3, 39%), 34 P (as superphosphate, 46%) and 52 K (as KCl, 60%). Sixteen pre-germinated seeds were sown in each pot. After emergence, plants were thinned to 12 per pot, and two of them were used as control plants for precise estimation of the growth stage.

Soil moisture was kept constant by frequent weighing of pots and addition of water to initial pot weight. Soil water stress was applied at the beginning of the following growth stages: tillering, shooting, heading and milk maturity. At these stages, the content of soil water was reduced to 40% of field water-holding capacity (FWC), near the wilting point pF = 3.4; after the first wilting symptoms were observed, the soil water content was again increased to the control level. In the control combination, water content in the soil was maintained at 70-90% FWC throughout the growing season. For each pot, the daily water evapotranspiration (E) was estimated using the following equation: $E = k\,(Wp - Wa - O)$, where: k is a coefficient of conversion from weight unit of water (g/pot) per 1 mm of precipitation, Wp is the pot weight on the preceding day at about 90% FWC, Wa is the actual pot weight and O is the weight of percolating water.

At harvest, the productive tillering, grain yield, straw yield and 1000-grain weight were determined. The degree of sensitivity to drought was estimated as a stress-induced reduction (in %) in the grain yield by a comparison of the stressed and control plants. Analysis of variance for the completely randomized design was performed. Fischer's procedure was used to test the effects of experimental variation sources.

Means of the daily water demand during the whole vegetation of three barley cultivars grown under optimal soil water supply are presented in Figure 1. There was a relatively broad stage-specific variation in the amount of evapotranspired water. Probably due to a limited leaf area in juvenile plants and diminished activity of older ones, the water use was low during the earlier growth stages and at the final growth phase. The requirements for water considerably increased at the shooting stage and were the highest at heading and milk maturity (mean daily water consumption by the plants in that period exceeded 7 mm). After that growth phase, the water requirements significantly decreased and attained a minimum at full maturity.

Considerable differences in water demand among the investigated cultivars were noticed only after the plants attained generative growth stages. The highest requirements for water were exhibited by the fodder cv. Rataj, while the brewery Maresi used the lowest amount of water.

The grain yield of plants grown under the optimal watering regime was assumed to be a measure of the potential grain productivity of spring barley. Means for the most important yield characteristics in barley plants grown under optimal (control) watering and those stressed at various growth stages are presented in Table 1. Yields of the spring barley grain under the conditions of optimal moisture of the soil varied between study years. The differences concerned all the studied varieties to the same extent. This was caused by the differentiated thermal conditions which had a different effect on the productivity of barley.

Many studies show that the changes in grain yield are mainly dependent on the changes in density of productive tillers and 1000-grain weight. An increase in ear number per unit area however, often leads to a decrease in 1000-grain weight (CARLSON et al. 1980, PECIO 1995). A similar direction of the changes in barley grain shape with a different number of productive tillers can be observed in our results (Table 1). The yield reduction caused by stress of the plants due to the simulated drought was similar in both years of the study. The conditions of drought caused a significant decline of all the examined traits of the crop. A negative effect of drought on the productivity of spring barley was visible in the initial periods of earing and milk maturity stages.

Analysis of variance corroborated the significance of genotypic and watering regime effects for the variation in major yield components (Table 1). Except for the straw yield and productive tillering in 1997, no significant genotype-watering interaction effects were observed for the studied yield traits.

Under the control watering regime, cv. Rataj yielded most grain (Figure 1b). However, this cultivar was the most drought sensitive and after water limitations applied at various growth stages cv. Rataj produced the lowest yield of grain of

Table 1. Means for major yield components of spring barley in water stress conditions applied at various growth stages, and summarized results of analysis of variance (significance of mean squares) for these characters

Stressed growth stage	Grain yield (g/pot)		Straw yield (g/pot)		1000-grain weght (g)		Productive tillering (no./plant)	
	1997	1998	1997	1998	1997	1998	1997	1998
Control[1)]	22.2	18.4	17.5	21.3	46.2	48.3	2.6	2.2
Tellering	21.6	18.0	16.7	19.0	46.6	48.7	2.6	2.2
Shooting	20.0	17.2	15.2	15.3	45.4	48.5	2.5	2.1
Heading	19.0	16.1	15.2	18.5	43.7	44.4	2.4	2.1
Milk maturity	18.5	15.8	16.7	19.8	38.9	40.6	2.6	2.2
LSD	2.23	0.97	1.39	1.85	2.46	2.67	0.17	0.09
Analysis of variance:								
Cultivars (A)	*	**	**	**	**	**	*	**
Stressed stages (B)	**	**	**	**	**	**	**	*
Interaction A × B			*				*	

[1)] water content in the soil was maintained at 70-90% of field water-holding capacity throughout the growing season

*,** significant by Fischer's test at the $P_{0.05}$ and $P_{0.01}$ levels, respectively

a relatively low endosperm size (Figures 1b, c). As presented in Figure 1b, cv. Rataj exhibited the highest sensitivity to stress conditions applied during later growth stages, and the drought-induced reductions in the grain yield of this variety reached 18-19%. In contrast, cv. Rudzik yielded less grain under optimal conditions, but its grain yield and 1000-grain weight were found to be the highest under the most stressful conditions and the yield reductions did not exceed 9-13%, suggesting the highest drought resistance of this cultivar.

Results presented in Figure 1b indicate that the highest decrease in the grain yield of barley was observed in plants grown under water limitations applied at the beginning of generative growth and during grain filling (the beginning of milk maturity). On average, the grain yield of stressed barley plants decreased by 14-16% in comparison with the control plants. Barley plants indicated a distinctly lower sensitivity to water stress during their earlier growth stages (vegetative growth).

As shown in Table 1, the drought-related growth limitations at the shooting stage inhibited tillering and reduced the number of productive tillers. Water deficit in the soil at the beginning of milk maturity considerably affected endosperm size, which was evidenced by the marked reductions in 1000-grain weight.

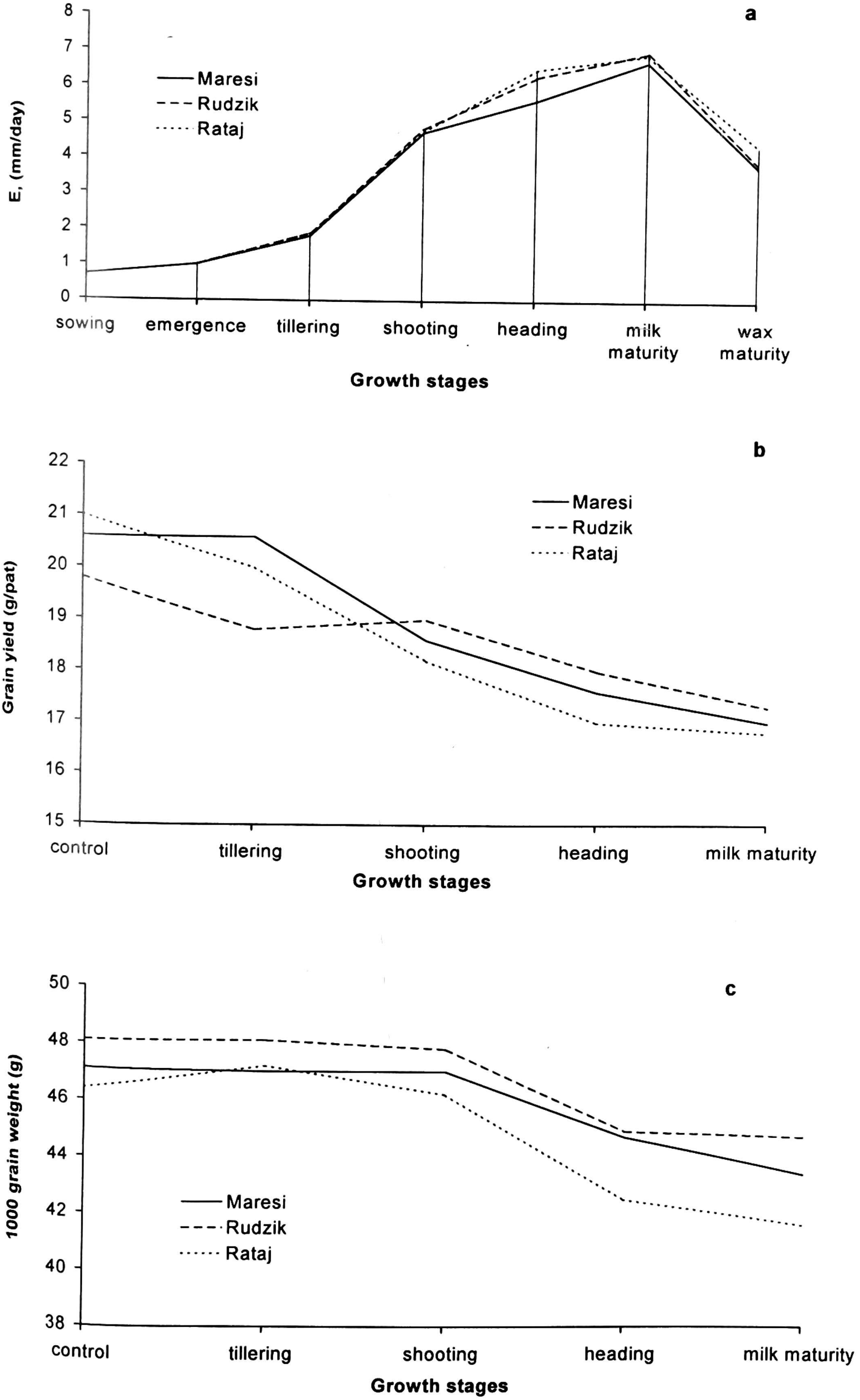

Figure 1. Response of barley varieties to water stress in the particular growth stages

a. Changes in the mean daily evapotranspiration in barley cultivars depending upon the growth stage at the optimal soil moisture. b. Grain yield of barley cultivars depending on the stressed growth stage. c. Differences in the 1000-grain weight of barley cultivars caused by water stress applied at different growth stages

In Poland, the unstable yielding associated with random fluctuations of climatic factors appears to be the main problem of the local crop production. Almost every year in different regions of our country and at different stages of the growing season, a deficit (rarely an excess) of soil water contributes to a marked yield reduction.

Results of the present study on barley corroborate, however, that water deficits at particular growth stages may have different consequences for grain yield. Moreover, the results seem to be a further reason to justify observations on the genetic determination of water use and different productivity of cultivars and species under water stress (GÓRECKI, GRZESIUK 1978, CARLSON et al. 1980, MARTYNIAK 1986, STARCK et al. 1995, GÓRNY 1999).

Our results suggest that depending on the genetic background cultivars of spring barley may exhibit a considerably different sensitivity to water stress and this variation may also result from non-uniform effects of stress conditions at particular stages of plant growth.

As shown in our study, the simulated drought at the heading and milk maturity stages may reduce grain yield by 9-19%. Such a stress effect at the generative growth is in accord with the theoretical responsibility of a hypothetical plant presented by HANSON and NELSEN (1980). Results of our previous study show, however, that under field conditions with limited possibilities of water balance, such water stress at these growth phases may contribute to greater consequences and depress the grain yield of spring barley even by 30% as, for example, in 1992 (MARTYNIAK et al. 1995).

In conclusion, the investigated cultivars of spring barley exhibited a different sensitivity to water stress applied at various growth stages. Genotypic variation in the drought-induced yield depression may considerably depend on the stressed growth stage and its expression tended to enhance at the generative growth stages at which such stress conditions caused the strongest negative effects.

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