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Response of common barley (*Hordeum vulgare* L.) physiological parameters to agricultural practices and meteorological conditions

Daiva JANUŠAUSKAITĖ, Ona AUŠKALNIENĖ, Dalia FEIZIENĖ, Virginijus FEIZA

Institute of Agriculture, Lithuanian Research Centre of Agriculture and Forestry
Instituto 1, Akademija, Kėdainiai distr., Lithuania
E-mail: daiva.janusauskaite@lzi.lt

Abstract

Little is known about the response of spring barley (*Hordeum vulgare* L.) physiological parameters to stand density, on which barley productivity depends. The aim was to establish the contrasts of physiological parameters between the different varieties and different stand densities under field conditions and the interaction between physiological parameters and meteorological factors of Lithuania (East Europe). The test involved three barley varieties and three stand densities. The measurements were made three times during the growing season. Varietal and stand density effect on photosynthetic rate, transpiration rate, and instantaneous water use efficiency was more strongly expressed in wet conditions compared with dry conditions. The spring barley varieties differed in the tolerance of meteorological factors throughout the growing season. The photosynthetic process was more intensive for the variety 'Barke' in dry and for 'Gustav' in wet weather conditions conditions. A medium density of 400 plants m^{-2} was the optimum. With the change in stand density, physiological parameters tended to decrease in most of the tested cases. The interaction of meteorological factors influenced the mean of photosynthetic rate across stand densities by 52.1, 67.1 and 73.6 % and the mean of transpiration rate by 63.3, 61.1 and 72.0 % for 'Aura DS', 'Barke' and 'Gustav', respectively.

Key words: gas exchange, *Hordeum vulgare*, stand density, varieties.

Introduction

Barley (*Hordeum*) is one of the most popular cereals belonging to the grass (*Poaceae*) family. It is now being cultivated in different parts of the world where different environmental factors are affecting plant growth, photosynthesis process and yield (Tambussi et al., 2005; Jiang et al., 2006; Kalaji et al., 2011). It is important for barley growers to better understand the factors affecting the photosynthetic productivity. Studies performed on different crops have indicated that the climate warming and changes in moisture and thermal regimes intensely influence the photosynthesis process (Gonzalez et al., 2010; Waraich et al., 2011 a; Zhao et al., 2011). Knowledge of the physiological traits that limit yield under inimical conditions provides new opportunities for future breeding and growing strategies (Tambussi et al., 2005; Gonzalez et al., 2010; Kalaji et al., 2011). Photosynthetic traits significantly differ between the different genotypes (Anyia, Herzog, 2004; Mamnouie et al., 2006), and between both open field and greenhouse growing conditions (Ibrahim, Jaafar, 2011). Intensity of photosynthesis varies throughout plant development stages (Tsialtas, Maslaris, 2008; Efthimiadou et al., 2010). The reduction of photosynthesis has direct effect on crop growth and yield (Gonzalez et al., 2010). This is important to consider while developing new technologies of barley cultivation. The factors related to the photosynthesis process, such as photosynthetic rate, transpiration, stomatal conductance and instantaneous water use efficiency can be used as selection criteria for the improvement of crop yield potential (Anyia, Herzog, 2004; Tambussi et al., 2005; Ibrahim, Jaafar, 2011). The relationship between photosynthetic parameters and chlorophyll index (SPAD) in the foliage is also important (Janušauskaitė et al., 2012).

There are no data about the influence of crop stand density on physiological parameters. Plant growth depends on photosynthesis which is affected by environmental factors such as temperature, nutrition and light (Cai et al., 2008; Niu et al., 2008). Conditions inimical to growth may cause stress, which may be apparent in morphological and physiological characteristics and represent integrated responses to multiple environmental factors. It was established that the low stand density (SD) allowed more energy to reach the soil, from which it was reflected, making a considerable contribution to the final temperature in the stand and water transpiration from soil and foliage (Anda, Løke, 2005). The plants in a denser stand have inter-competition pressure not only for nutrition, but also for light, and a lower light intensity inside the stand leads to a lower carbon gain of the individual plants (Del Pozo, Dennett, 1999). As a result, an increase in the SD could be considered a stress condition.

The effect of SD on physiological characteristics of spring barley grown under field conditions has not been extensively studied. In addition, there is not enough information about the effect of the different seed rate on photosynthetic rate (A), transpiration rate (E), stomatal conductance (gs) and instantaneous water use efficiency (WUE*i*) of widely cultivated varieties in our region. The main objective of the present study was to establish the contrasts in A, E, gs and WUE*i* between the different varieties and different stand densities throughout development stages exclusively under open field conditions. In addition, the interaction between physiological parameters and meteorological factors under field conditions of Lithuania (East Europe) was also assessed in this study.

Materials and methods

Study site. Field experiments were carried out at the Lithuanian Institute of Agriculture (currently – Lithuanian Research Centre for Agriculture and Forestry) in Central Lithuania (55°23′50″ N and 23°51′40″ E) during 2008–2009. The soil type of the experimental field is an *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*). According to fractions of soil aggregates: 52–54% sand (2.0–0.05 mm), 29–32% silt (0.05–0.002 mm) and 14–19% clay (<0.002 mm), soil was medium loam. The concentration of available P_2O_5 (A-L method) varied from 74 to 122 mg kg^{-1}, available K_2O (A-L method) from 133 to 199 mg kg^{-1}, pH $_{KCl}$ from 6.0 to 6.1, humus from 1.7% to 2.3% in 0–25 cm soil layer.

Plant material and agricultural practices. The recommended stand density of spring barley in Central Lithuania is 4 million plants per hectare. Treatments included three stand densities (SDs) with the seed rates of 200 (SD I), 400 (SD II) and 600 (SD III) plants m^{-2} and three spring barley (*Hordeum vulgare* L.) varieties 'Aura DS', 'Barke' and 'Gustav'. The plants of variety 'Aura DS' are broad-leaved, tall, mid maturity. Variety 'Barke' is of middle shading ability, medium tall, quite broad-leaved. The plants of variety 'Gustav' are of the lowest shading ability with short stems. The experimental design was a split plot with four replications. Barley varieties were laid out in the main plot and the stand density in the subplot. Spring wheat (*Triticum aestivum* L.) was a pre-crop. Spring barley was fertilized with $N_{60}P_{60}K_{60}$ before sowing. The soil was ploughed in the autumn. Spring barley was sown with a small plot drill "Wintersteiger Tool Carrier 2700" (Germany) in spring. The row spacing was 12 cm, sowing depth 2–3 cm. The herbicides were applied: in 2008 – MCPA (MCPA) (0.75 l ha^{-1}) and Lintur 70 WG (triasulfuron + dicamba) (120 g ha^{-1}) and in 2009 – Lintur 70 WG (120 g ha^{-1}). The stand crop was sprayed with fungicides: in 2008 – Archer Top 400 EC (propiconazole + fenpropidin) (1.0 l ha^{-1}), 2009 Falcon 460 EC (tebuconazole + triadimenol + spiroxamin) (0.6 l ha^{-1}).

Leaf gas exchange measurements. Leaf gas exchange measurements including photosynthetic rate (A), transpiration rate (E), and stomatal conductance (gs) were determined using a portable gas analyser SRS-1000 (ADC BioScientific Ltd., UK). The SRS-1000 system consists of the compact programming console and leaf chamber, which has a square (6.25 cm^2) aperture sealed. The attached flag leaf was placed into the chamber and A was recorded in data logger in about two minutes, when no noticeable changes in leaf respiration were registered. The measurements were made from 2 p.m. till 4 p.m. four times on clear days throughout growing season – at first node growth stage (GS) (corresponding to code BBCH 31), at booting GS (BBCH 45), end of heading GS (BBCH 59) and at watery ripe (BBCH 71) in two replications of each trial treatment. The dates of the investigated GS in 2008 were 29 May, 9 June, 26 June and 11 July, in 2009 – 10 June, 17 June, 29 June and 8 July. The measurements were made on a randomly selected first fully expanded leaf from the top of each plot. The values of A and E were used to calculate the instantaneous water use efficiency (WUE*i* = A/E).

Meteorological data. Weather conditions were one of the tested parameters. The weather conditions varied throughout the experimental years (Table 1). The period of May–July in 2008, compared to the long term mean, was dry – as little as 21% of long-term mean of rainfall fell in May, 67% in June, and 64% in July, respectively. However, the air temperature was more or less similar to the long-term mean: in May it was equal, in June 0.5°C and in July 0.6°C above the long-term mean. In 2009 like in 2008, there was a shortage of rainfall in May when 52% of the long-term mean fell, nonetheless in June and July the total rainfall amounted to 270% and 123% of the long-term mean, respectively. The mean air temperature was similar to that in 2008 – 0.5°C above the long-term mean in May and July and in June it was 1.0°C below the long-term mean.

Table 1. Meteorological conditions during the spring barley growing season (Dotnuva Weather Station)

Month	2008				2009			
	Air temperature °C		Precipitation mm		Air temperature °C		Precipitation mm	
	Monthly mean	Difference from long-term mean	Monthly mean	Difference from long-term mean	Monthly mean	Difference from long-term mean	Monthly mean	Difference from long-term mean
April	8.8	+3.0	38.7	+1.5	8.8	+3.0	13.1	−23.8
May	12.2	0	13.2	−38.9	12.7	+0.5	26.7	−25.1
June	16.1	+0.5	49.2	−11.9	14.6	−1.0	168.6	+106.2
July	18.2	+0.6	47.6	−25.7	18.1	+0.5	90.0	+16.6
August	18.0	+1.3	90.8	+17.0	16.8	+0.1	67.1	−6.6

Statistical analysis. Analysis of variance ($P < 0.05$) based on a three-factorial (factor A – variety, factor B – SD, factor C – GS) split-plot design model were performed using the *ANOVA*, *STATISTICA* package. Significance of treatment effects was analyzed by the Fisher LSD (least significant difference). Also, the experimental data were processed by correlation – regression analysis method using *STAT-ENG*.

Results and discussion

The meteorological conditions were diverse in the experimental years (Table 1), therefore the results were separately analysed and discussed for 2008 and 2009. The varietal influence on photosynthetic rate (A) and instantaneous water use efficiency (WUE*i*) was significant ($P \leq 0.05$) in 2008 (Table 2). Stand density (SD) significantly ($P \leq 0.05$, $P \leq 0.01$) influenced transpiration rate (E) and WUE*i*. The growth stage (GS) significantly influenced ($P \leq 0.05$) all parameters – A, E, WUE*i* and stomatal conductance (gs) in 2008.

The influence of variety and SD on A and WUE*i* was significant at $P \leq 0.01$ and on E was significant at $P \leq 0.05$ in 2009. All parameters were influenced by GS at $P \leq 0.01$. The variety and stand density effect on gs was insignificant in both years.

Table 2. Analysis of variance of photosynthetic parameters

Indicator	Factor						
	Variety (factor A)	SD (factor B)	GS (factor C)	A × B	A × C	B × C	A × B × C
2008							
A	*	ns	**	ns	*	ns	ns
E	ns	*	**	ns	*	ns	ns
WUE*i*	*	**	**	ns	ns	ns	ns
gs	ns	ns	**	ns	ns	ns	ns
2009							
A	**	**	**	**	**	ns	**
E	*	*	**	ns	**	ns	*
WUE*i*	**	**	**	ns	**	ns	**
gs	ns	ns	**	*	**	ns	**

SD – stand density, GS – growth stage, A – photosynthetic rate, E – transpiration rate, WUE*i* – instantaneous water use efficiency, gs – stomatal conductance; * – $P \leq 0.05$, ** – $P \leq 0.01$, n.s. – non-significant

Variation of photosynthetic rate (A) and transpiration rate (E) of spring barley. The variety ‘Barke’ was characterized by higher A in 2008. Averaged across SD, mean of A was highest for the variety ‘Barke’ in three cases out of four – at BBCH 31, BBCH 45 and at BBCH 71 and was 8.10, 13.12 and 2.71 µmol CO_2 m^{-2} s^{-1}, respectively (Table 3). The differences between A values of the variety ‘Barke’ and mean of trial were significant at intensive growth period of barley and they were found to be 0.87 µmol CO_2 m^{-2} s^{-1} at BBCH 31 and 2.13 µmol CO_2 m^{-2} s^{-1} at BBCH 45.

Table 3. Effects of variety and stand density (SD) on photosynthetic rate (A, µmol CO_2 m^{-2} s^{-1}) and transpiration rate (E, mmol H_2O m^{-2} s^{-1}), in 2008

Variety	SD	BBCH 31		BBCH 45		BBCH 59		BBCH 71	
		A	E	A	E	A	E	A	E
‘Aura DS’	SD I	7.52	1.61	10.14	2.91	7.96	2.88	3.33	1.80
	SD II	6.33	1.15	9.92	2.56	9.57	3.17	2.06	1.54
	SD III	6.97	1.58	9.07	2.60	7.47	2.82	2.40	1.37
‘Barke’	SD I	8.61	1.86	12.20	2.76	7.01	3.06	3.38	1.72
	SD II	7.42	1.62	12.76	3.08	8.88	2.24	2.39	1.33
	SD III	8.28	1.88	14.39	2.85	4.27	2.32	2.36	1.86
‘Gustav’	SD I	7.45	1.64	9.28	2.55	8.87	3.64	2.22	1.39
	SD II	5.13	1.67	9.63	3.33	6.88	3.13	0.46	1.08
	SD III	7.36	1.47	11.56	2.82	8.47	3.06	1.31	1.01
Mean across SDs[a]									
‘Aura DS’		6.94 b	1.44 c	9.71 c	2.69 b	8.33 b	2.96 b	2.59 b	1.57 b
‘Barke’		8.10 a	1.79 a	13.12 a	2.90 b	6.72 b	2.54 c	2.71 b	1.63 b
‘Gustav’		6.64 c	1.59 b	10.16 b	2.90 b	8.07 b	3.28 a	1.33 c	1.16 c
Mean across varieties[a]									
	SD I	7.86 b	1.70 b	10.54 b	2.74 b	7.95 b	3.19 a	2.97 a	1.63 b
	SD II	6.29 c	1.48 c	10.77 b	2.99 b	8.44 b	2.85 b	1.63 b	1.32 b
	SD III	7.53 b	1.64 b	11.67 b	2.76 b	6.74 b	2.74 b	2.02 b	1.41 b
Mean of trial		7.23	1.61	10.99	2.83	7.71	2.92	2.21	1.45
Significance									
Variety (factor A)		*	**	**	ns	ns	**	*	ns
SD (factor B)		ns	ns	ns	ns	ns	ns	ns	ns
A × B		ns	ns	ns	ns	ns	ns	ns	ns

Note. BBCH 31 – stem elongation, first node, BBCH 45 – booting, BBCH 59 – end of heading, BBCH 71 – watery ripe; * – $P \leq 0.05$, ** – $P \leq 0.01$, [a] – numbers followed by different letter within a set of the column are significantly different at $P \leq 0.05$ by the least square means test.

A mean of trial varied throughout GS in 2009 (Table 4). The maximum of A was established at BBCH 31. A mean of trial decreased by 30% at BBCH 45, and by 33.1% at BBCH 59 and by 35.0% at BBCH 71 compared with previous assessment at BBCH 31, BBCH 45 and BBCH 59, respectively.

Table 4. Effects of variety and stand density (SD) on photosynthetic rate (A, µmol CO_2 m^{-2} s^{-1}) and transpiration rate (E, mmol H_2O m^{-2} s^{-1}), in 2009

Variety	SD	BBCH 31		BBCH 45		BBCH 59		BBCH 71	
		A	E	A	E	A	E	A	E
‘Aura DS’	SD I	6.23	3.64	5.27	3.08	2.03	2.39	0.75	2.92
	SD II	8.42	3.32	7.62	3.11	3.14	2.42	2.28	3.61
	SD III	7.53	3.43	3.46	2.55	5.55	2.85	3.71	2.80
‘Barke’	SD I	11.38	3.92	6.12	3.00	4.93	4.50	3.87	2.86
	SD II	11.98	3.55	8.52	3.31	6.23	3.18	3.47	2.54
	SD III	9.98	3.67	8.38	3.32	2.93	3.83	2.33	2.47
‘Gustav’	SD I	9.95	4.07	7.97	3.16	7.26	4.04	5.07	2.71
	SD II	14.87	3.96	7.56	3.06	5.75	3.26	3.17	0.98
	SD III	14.48	4.23	10.87	3.58	6.21	3.51	4.02	1.62
Mean across SDs[a]									
‘Aura DS’		7.39 c	3.46 c	5.45 c	2.91 b	3.57 c	2.55 c	2.25 c	3.11 a
‘Barke’		11.11 b	3.71 b	7.67 b	3.21 b	4.70 b	3.83 a	3.22 b	2.62 b
‘Gustav’		13.10 a	4.09 a	8.80 a	3.27 b	6.41 a	3.60 b	4.08 a	1.77 c
Mean across varieties[a]									
	SD I	9.18 c	3.87 b	6.45 c	3.08 b	4.74 b	3.64 b	3.23 a	2.83 a
	SD II	11.76 a	3.61 b	7.90 b	3.16 b	5.04 b	2.95 c	2.97 a	2.38 b
	SD III	10.66 b	3.78 b	7.57 b	3.15 b	4.89 b	3.39 b	3.35 a	2.30 b
Mean of trial		10.53	3.75	7.31	3.13	4.89	3.33	3.18	2.50
Significance									
Variety (factor A)		**	**	**	ns	**	**	*	**
SD (factor B)		**	ns	ns	ns	ns	ns	ns	*
A × B		*	ns	**	ns	*	ns	*	**

Explanations under Table 3

Under wet weather conditions in 2009, the response of the tested varieties differed in A and E compared with 2008. A was the highest for the variety ‘Gustav’ at all measurements (Table 4). Contrasts of A values ‘Gustav’ *vs*. trial mean were 24.4, 20.4, 31.1 and 28.3 % higher at BBCH 31, BBCH 45, BBCH 59 and BBCH 71, respectively than the trial mean. Contrasts were significant and positive at all GS. The lowest A was established for the variety ‘Aura DS’ and contrasts ‘Aura DS’ *vs*. trial mean was significant and negative in all tested cases. All contrasts for ‘Gustav’ *vs*. trial mean were not significant. The study confirmed the existence of varietal differences in A of other plants. The influence of variety on A was significant ($P \leq 0.01$) for 10 genotypes of winter wheat (Hui et al., 2008) and for six varieties of durum wheat (Abbad et al., 2004). The A values differed significantly amongst the ten genotypes by 3.01–5.09 µmol CO_2 m^{-2} s^{-1} in cowpea (Anyia, Herzog, 2004). The differences in A among the seven rice varieties at each GS ranged between about 6 and 11 µmol CO_2 m^{-2} s^{-1} (Takai et al., 2010). The A values of the flag leaf of winter wheat (*Triticum aestivum* L.) increased with cultivar development (Tian et al., 2011). Leaf A is closely related with many environmental factors, influencing plant physiology. The negative influence on A is exerted by inadequate nutrition (Fois et al., 2009) and the temperature of the leaf tissue (Niu et al., 2008; Ko, Piccinni, 2009; Takai et al., 2010). A limited water supply inhibits A of plants, causes changes of chlorophyll contents and components and damage to photosynthetic apparatus (Abbad et al., 2004; Waraich et al., 2011 a). Canopy architecture plays a significant role in light capture ability and A of canopy (Brooks et al., 2000). The arrangement, when the plants have vertical leaves at the top, becoming more horizontal near the bottom, spreads the light evenly between canopy, resulting in an increase in photosynthetic CO_2 uptake, compared to the plant varieties with mostly horizontal leaves (Long et al., 2006). It is likely that in our experiment the different leaf architecture of the tested barley cultivars may have influenced A differences between cultivars.

Averaged across varieties, comparable contrasts of A between different SDs were significant ($P \leq 0.05$) in 25% of the tested cases, i.e. for SD II *vs*. SD I at BBCH 31 and at BBCH 71 in 2008 (Table 3). Averaged across varieties in 2009, A comparable contrasts between different SDs were positive and the highest A was in SD II, but significant only in two cases, i.e. for SD II *vs*. SD I at BBCH 31 – 2.57 µmol CO_2 m^{-2} s^{-1} ($P \leq 0.01$) and at BBCH 45 – 1.44 µmol CO_2 m^{-2} s^{-1} ($P \leq 0.05$) (Table 4). Fang et al. (2010) found that increased seeding density reduced ($P < 0.05$) the A of flag leaf at winter wheat anthesis. There are data suggesting that A is affected by row spacing, not only by stand density; however, a more intensive rise of photosynthetic productivity was registered for increased sunflower hybrid density (Aksyonov, 2007).

A mean of trial differed throughout GS in 2008 (Table 3). A reached the maximum at BBCH 45 and was higher by 52% compared with the first assessment at BBCH 31. A mean of trial decreased by 30% at BBCH 59 and by 71% at BBCH 71 compared with previous assessment at BBCH 45 and BBCH 59, respectively. The decline of A mean of trial in 2009 was more moderate than in 2008. The A mean of trial decreased by 30.5% at BBCH 45, 33.1% at BBCH 59 and 35.0% at BBCH 71, compared with previous assessment at BBCH 31, BBCH 45 and BBCH 59, respectively (Table 4). The decline of A was found also for rice (Takai et al., 2010), maize (Efthimiadou et al., 2010), sugar beet (Tsialtas, Maslaris, 2008), cotton (Ko, Piccinni, 2009) during the growing season. Gutierrez et al. (2009) found that A declined between heading and 10–13 days after anthesis. Other authors indicated that the A of wheat flag leaves initially increased after anthesis, reaching a maximum on the 21st day after anthesis, then gradually decreased (Cai et al., 2008).

Varietal responses of E were very similar to A in 2008. Averaged across SDs, the highest E values were determined for 'Barke' and they were by 11.1, 2.4 and 12.4 % higher at BBCH 31, BBCH 45, and BBCH 71, respectively than the trial mean (Table 3). Averaged across SDs in 2009, the highest E were determined for variety 'Gustav' at BBCH 31, BBCH 45 and the E values were higher by 0.33 mmol H_2O m^{-2} s^{-1} (9.1%) and 0.14 mmol H_2O m^{-2} s^{-1} (4.5%), respectively than the trial mean (Table 4). The difference at BBCH 31 was significant ($P \leq 0.01$). At the successive GS, the highest E was of 'Barke' and 'Aura DS' and was higher by 0.51 mmol H_2O m^{-2} s^{-1} (15.0%, $P \leq 0.01$) and 0.61 mmol H_2O m^{-2} s^{-1} (24.4%, $P \leq 0.01$) compared with trial mean, respectively. In 2009 June third ten-day period, before a third measurement at BBCH 59, plenty of rainfall fell – 78.3 mm, the mean air temperature was 17.9°C, i.e. 2.3°C above the long-term mean. With changing humidity and temperature, the response of barley varieties to environmental conditions differed in E. Thus, both varieties 'Barke' and 'Aura DS' responded more sensitively to moisture abundance than 'Gustav'. The results of the present study are in conformity with the findings of Anyia and Herzog (2004) who reported that well-watered plants had clearly the highest E and A, compared with water stressed, but contrasts between varieties were different. Waraich et al. (2011 b) also indicated that sufficient water supply significantly ($P \leq 0.01$) affected the E and gs of wheat and the limiting irrigation resulted in a decrease of E ranging from 12% to 33%.

The study of other researchers confirmed the existence of varietal differences in E. Gorny and Garczynski (2002) reported that cultivars of winter wheat contributed to the significant (0.339, $P \leq 0.01$) variation of E. However, the result of the study with naked and hulled oat (*Avena sativa* L.) revealed the contrary fact; there were no differences in E between the two varieties (Zhao et al., 2011). Averaged across varieties, with increasing SD, E values tended to decrease in 2008 (Table 3). The highest E was in SD I at BBCH 31, BBCH 59 and BBCH 71 and in SD II at BBCH 45. Contrasts between different SDs were significant in two of the tested cases, for SD II *vs*. SD I at BBCH 31 and BBCH 59 ($P \leq 0.05$) and SD III *vs*. SD II at BBCH 59 ($P \leq 0.05$). Averaged across varieties in 2009, the highest E was established for the lowest stand density SD I in most cases (Table 4). The differences between SDs were significant in 25% of the tested cases. E differed for SD II *vs*. SD I by 0.69 mmol H_2O m^{-2} s^{-1} ($P \leq 0.01$) and by 0.45 mmol H_2O m^{-2} s^{-1} ($P \leq 0.05$), respectively at BBCH 59 and BBCH 71, and for SR III *vs*. SR I differed by 0.53 mmol H_2O m^{-2} s^{-1} ($P \leq 0.01$) at BBCH 59. In general, E of flag leaf decreased with increasing SD. As a result, an increase in the SD could be considered a stress condition. The plants in a denser stand have inter-competition pressure not only for nutrition, but also for soil moisture and light and a lower water supply and light intensity inside the stand leads to a lower carbon gain of the individual plants (Del Pozo, Dennett, 1999). In our study, the decrease of E can be explained by the assumption that reduction of humidity, light and nutrients, especially potassium and magnesium, in the denser crop caused transpiration decreases as indicated by other researchers (Waraich et al., 2011 a).

Variation of instantaneous water use efficiency (WUEi) and stomatal conductance (gs) of spring barley. The mean across SD of instantaneous WUE*i* was the highest for variety 'Aura DS' in most cases, the values were higher by 7.9% ($P \leq 0.05$), 9.7% and 18.5% at BBCH 31, BBCH 59 and BBCH 71, respectively, compared with mean of trial in 2008 (Table 5). At BBCH 45, the highest (6.95 µmol mmol^{-1}) WUE*i* was established for variety 'Barke' and the value was 35.2% higher than mean of trial at the same GS. Under dry conditions during growth period (Table 1), WUE*i* decreased in the following sequence: 'Aura DS' > 'Barke' > 'Gustav'.

Table 5. Effects of variety and stand density (SD) on instantaneous water use efficiency (WUE*i*) (µmol mmol^{-1}) and stomatal conductance (gs) (mol m^{-2} s^{-1}) in 2008

Variety	SD	BBCH 31		BBCH 45		BBCH 59		BBCH 71	
		WUE*i*	gs	WUE*i*	gs	WUE*i*	gs	WUE*i*	gs
'Aura DS'	SD I	4.62	0.51	3.60	0.17	2.73	0.27	2.06	1.02
	SD II	5.53	0.23	3.93	0.12	2.99	0.27	1.46	0.22
	SD III	4.55	0.60	3.40	0.13	3.08	0.27	2.07	0.12
'Barke'	SD I	4.62	0.74	9.91	0.16	2.08	0.38	1.89	0.19
	SD II	4.61	0.40	5.49	0.18	3.92	0.17	1.95	0.10
	SD III	4.41	0.65	5.45	0.16	1.81	0.17	1.27	0.15
'Gustav'	SD I	4.53	0.65	3.85	0.11	2.48	0.37	1.57	0.11
	SD II	3.02	0.63	2.87	0.18	2.16	0.29	0.58	0.07
	SD III	4.99	0.40	7.74	0.18	2.82	0.24	1.24	0.06
Mean across SDs[a]									
'Aura DS'		4.90 a	0.14 b	3.64 b	0.14 b	2.94 b	0.27 b	1.86 b	0.46 b
'Barke'		4.55 b	0.16 b	6.95 b	0.16 b	2.61 b	0.24 b	1.70 b	0.14 b
'Gustav'		4.18 c	0.16 b	4.82 b	0.16 b	2.49 b	0.30 b	1.13 b	0.08 b
Mean across varieties[a]									
	SD I	4.59 b	0.14 b	5.79 b	0.14 b	2.43 b	0.34 a	1.84 b	0.44 b
	SD II	4.38 b	0.16 b	4.10 b	0.16 b	3.03 b	0.24 b	1.33 b	0.13 b
	SD III	4.65 b	0.16 b	5.53 b	0.15 b	2.57 b	0.23 b	1.53 b	0.11 b
Mean of trial		4.54	0.15	5.14	0.15	2.68	0.27	1.57	0.23
Significance									
Variety (factor A)		*	ns	ns	ns	ns	ns	ns	ns
SD (factor B)		ns	ns	ns	ns	ns	ns	ns	ns
A × B		**	ns	ns	ns	ns	ns	ns	ns

Explanations under Table 3

Under wet weather conditions in 2009 (Table 1), averaged across SD, the highest WUE*i* was recorded for 'Gustav', and the values decreased in the following sequence: 'Gustav' > 'Barke' > 'Aura DS' (Table 6). WUE*i* for 'Gustav' was higher by 15.2% ($P \leq 0.01$), 16.4% ($P \leq 0.01$), 24.2% and 68.2% ($P \leq 0.01$) at BBCH 31, BBCH 45, BBCH 59 and BBCH 71, respectively, compared to mean of trial.

Table 6. Effects of variety and stand density (SD) on instantaneous water use efficiency (WUE*i*) (µmol mmol^{-1}) and stomatal conductance (gs) (mol m^{-2} s^{-1}) in 2009

Variety	SD	BBCH 31		BBCH 45		BBCH 59		BBCH 71	
		WUE*i*	gs	WUE*i*	gs	WUE*i*	gs	WUE*i*	gs
'Aura DS'	SD I	1.72	0.57	1.69	0.57	0.86	0.63	0.27	0.50
	SD II	2.60	0.55	2.45	0.66	1.26	0.54	0.63	0.39
	SD III	2.19	0.63	1.37	0.53	2.11	0.79	1.34	0.41
'Barke'	SD I	2.88	0.61	2.00	0.61	1.08	0.98	1.34	0.46
	SD II	3.47	0.57	2.57	0.80	1.94	2.62	1.36	0.57
	SD III	2.76	0.71	2.65	0.75	0.83	0.96	0.95	0.59
'Gustav'	SD I	2.45	0.55	2.53	0.53	1.91	4.58	2.13	0.78
	SD II	3.80	0.74	2.53	0.63	1.86	0.86	3.16	2.83
	SD III	3.49	0.59	3.05	0.79	1.94	1.04	2.18	0.75
Mean across SDs[a]									
'Aura DS'		2.17 c	0.58 b	1.84 c	0.59 b	1.41 b	0.65 c	0.75 c	0.43 c
'Barke'		3.04 b	0.63 b	2.41 b	0.72 b	1.29 b	1.52 b	1.22b	0.53 b
'Gustav'		3.25 a	0.62 b	2.70 a	0.65 b	1.90 c	2.16 a	2.49 a	1.45 a
Mean across varieties[a]									
	SD I	2.35 c	0.57 b	2.07 c	0.57 b	1.28 b	2.06 b	1.25 b	0.52 b
	SD II	3.29 a	0.62 b	2.52 a	0.69 b	1.69 b	1.34 b	1.72 b	1.24 a
	SD III	2.81 b	0.64 b	2.36 b	0.69 b	1.62 b	0.93 a	1.49 b	0.65 b
Mean of trial		2.82	0.61	2.32	0.65	1.53	1.44	1.48	0.80
Significance									
Variety (factor A)		**	ns	**	ns	ns	*	**	**
SD (factor B)		**	ns	*	ns	ns	ns	ns	*
A × B		*	ns	**	ns	ns	*	*	**

Explanations under Table 3

WUE*i* is determined from the simultaneous measurement of CO_2 assimilation (µmol CO_2 m^{-2} s^{-1}) and transpiration (mmol H_2O m^{-2} s^{-1}) of a leaf or whole plant at a given point in time (Tian et al., 2011). Knowledge of the physiological traits that limit yields has improved in recent years (Jiang et al., 2006; Tsialtas, Maslaris, 2008; Ko, Piccinni, 2009). This has created new opportunities for plant breeders who can now focus on new genotypes with higher WUE*i* (Tambussi et al., 2005; Hui et al., 2008). Differences of WUE*i* between varieties were also indicated by other researchers. WUE*i* of winter wheat cultivars ranged from 7.74 to 9.61 mmol mol^{-1} and cultivars contributed to the significant ($P \leq 0.01$) variation of the leaf photosynthetic characteristics (Gorny, Garczynski, 2002). However, in contrast to our result, Jiang et al. (2006) and Zhao et al. (2011) reported that there were no significant differences in WUE*i* between 14 barley and 2 oat genotypes, respectively. With increasing spring barley SDs, mean of WUE*i* across varieties had unequal trend at the different GS under dry weather conditions in 2008 (Table 5). The differences between SDs of WUE*i* were insignificant (Table 5). The highest WUE*i* – 5.79 µmol mmol^{-1} and 1.84 µmol mmol^{-1} was in the lowest SD at BBCH 45 and BBCH 71, respectively, and in SD III and SD II at the other GS. Averaged across varieties in 2009, the highest WUE*i* was established in SD II at all measurements, and contrasts SD II *vs*. SD I were higher by 40.0% at BBCH 31 ($P \leq 0.01$), 21.7% at BBCH 45 ($P \leq 0.05$), 32.0% at BBCH 59 and 37.6% at BBCH 71 ($P \leq 0.05$). The values decreased in the following sequence: SD II > SD III > SD I (Table 6).

Mean WUEi of trial declined from BBCH 59 in both years. Genotypic response of gs was similar to E in most of the tested cases in 2008 (Table 5). Averaged across SD, gs decreased in the following sequence: 'Gustav' > 'Barke' > 'Aura DS' in most of the measurements in 2009 (Table 6). Significant positive contrast ($P \leq 0.01$) was only for 'Gustav' *vs*. trial mean at BBCH 71. The contrast 'Aura DS' *vs*. trial mean was significant negative ($P \leq 0.01$) at BBCH 59 and BBCH 71. The study of other researchers confirmed the existence of varietal differences in gs of rice, the differences in gs ranged between about 0.8 and 0.9 mol m^{-2} s^{-1} (Takai et al., 2010). The gs of barley breeding lines ranged from 0.022 to 0.057 mol m^{-2} s^{-1} ($P \leq 0.001$) (Jiang et al., 2006). Gonzalez et al. (2010) also confirms significant varietal influence on gs for barley ($P < 0.001$). Varietal influence on gs can be explained by different response of varieties to solar radiation and leaf temperature differences. There are data suggesting the existence of strong relationship between canopy temperature and both gs and A. Canopy temperature was significantly correlated with gs ($r = -0.93$, $P < 0.01$) and with A ($r = -0.91$, $P < 0.01$) (Takai et al., 2010). The differences in leaf temperatures between varieties ranged between 0.9°C and 1.7°C. Ko and Piccinni (2009) have also reported that leaf temperature strongly and significantly correlates with A and gs. However, conflicting data have been obtained by Zhao et al. (2011) who states that varietal influence on gs was not significant for two varieties of oats. Averaged across varieties, gs was similar in different SDs at BBCH 31 and BBCH 45 in 2008 (Table 5). The highest gs (0.34 and 0.44 mol m^{-2} s^{-1}) were in the lowest SD I, respectively at BBCH 59 and BBCH 71. The contrasts SD II *vs*. SD I and SD III *vs*. SD I were significant ($P \leq 0.05$) only at BBCH 59 in 2008. The contrasts SD III *vs*. SD I were significant ($P \leq 0.05$) at BBCH 59, SD II *vs*. SD I and SD II *vs*. SD III were significant ($P \leq 0.05$) at BBCH 71 (Table 6).

Relationship between phyciological parameters and meteorological factors. The leaf gas exchange parameters could be viewed as sensitive response factors of the plant to abiotic stress (Zhao et al., 2011). The simple correlation analysis confirmed the existence of the correlation between the physiological parameters of spring barley and meteorological factors from sowing throughout the growing season. However, differences among the SDs and varieties were noticed in the strength of the relationship among the variables as shown by the values of the correlation coefficients in Table 7.

Table 7. Simple correlation coefficients between physiological parameters and meteorological factors (2008–2009)

	Mean air temperature °C	Precipitation mm	GDD ≥ 5°C[1]	GDD ≥ 10°C[2]	Sunshine duration h	Relative air humidity %
			A			
			Mean across varieties			
SD I	−0.280*	−0.459**	−0.585**	−0.581**	−0.524**	−0.233*
SD II	−0.316**	−0.374**	−0.575**	−0.587**	−0.495**	−0.325**
SD III	−0.291**	−0.380**	−0.620**	−0.618**	−0.560**	−0.131
			Mean across SDs			
'Aura DS'	−0.273*	−0.528**	−0.537**	−0.531**	−0.466*	−0.307**
'Barke'	−0.287*	−0.458**	−0.661**	−0.654**	−0.594**	−0.200
'Gustav'	−0.337**	−0.263*	−0.599**	−0.616**	−0.530**	−0.116
			E			
			Mean across varieties			
SD I	0.012	0.208	−0.098	−0.132	−0.059	0.57**
SD II	−0.091	0.080	−0.216	−0.245*	−0.157	0.469**
SD III	−0.057	0.112	−0.216	−0.254*	−0.176	0.514**
			Mean across SDs			
'Aura DS'	−0.076	0.247*	−0.046	−0.057	0.020	0.504*
'Barke'	0.041	0.214	−0.182	−0.220	−0.162	0.580**
'Gustav'	−0.092	−0.015	−0.273*	−0.322**	−0.220	0.486**
			gs			
			Mean across varieties			
SD I	0.194	0.221	0.037	0.011	−0.018	0.271*
SD II	0.100	0.497**	0.036	0.031	−0.014	0.406**
SD III	−0.135	0.377**	−0.271*	−0.301**	−0.334**	0.409**
			Mean across SDs			
'Aura DS'	−0.036	0.144	0.012	−0.009	−0.014	0.193
'Barke'	0.088	0.342**	−0.142	−0.181	−0.217	0.424**
'Gustav'	0.179	0.425**	0.034	0.024	−0.023	0.363**
			WUE*i*			
			Mean across varieties			
SD I	−0.098	−0.316**	−0.320**	−0.298**	−0.305**	−0.352**
SD II	−0.317**	−0.404**	−0.573**	−0.553**	−0.547**	−0.399**
SD III	−0.158	−0.359**	−0.436**	−0.412**	−0.418**	−0.386**
			Mean across SDs			
'Aura DS'	−0.308**	−0.617**	−0.584**	−0.561**	−0.578**	−0.697**
'Barke'	−0.102	−0.341**	−0.358**	−0.337**	−0.332**	−0.332**
'Gustav'	−0.187	−0.221	−0.427**	−0.404**	−0.410**	−0.258*

Notes. [1] – baseline temperature used for growing degree days (GDD) computation was 5°C, [2] – baseline temperature used for growing degree days (GDD) computation was 10°C. A – photosynthetic rate, SD – stand density, E – transpiration rate, gs – stomatal conductance, WUE*i* – instantaneous water use efficiency; *, ** – relationship between indices is significant at $P \leq 0.05$ and $P \leq 0.01$, respectively. Mean values of air temperature (12.5 < °C < 18.7 and 12.2 < °C < 22.8), precipitation (11.6 < mm < 66.6 and 35.8 < mm < 231.6), GDD ≥ 5°C (200.1 < °C < 746.6 and 332.2 < °C < 678.9), GDD ≥ 10°C (62.1 < °C < 358.4 and 126.5 < °C < 346.9), sunshine duration (267.7 < h < 792.6 and 437.1 < h < 723.3), relative air humidity (49 < % < 61 and 68 < % < 79) ranged from sowing to last measurement, respectively in 2008 and 2009.

The mean of A across varieties and across SDs negatively correlated with all meteorological factors and the correlation was significant ($P \leq 0.05$ and $P \leq 0.01$) in most of the tested cases. Averaged across varieties and across SDs, mean of E significantly and positively correlated ($P \leq 0.05$ and $P \leq 0.01$) with relative air humidity. The correlation coefficients revealed that the mean of E across varieties and GDD ≥ 10°C were negatively correlated ($P \leq 0.05$) in SD II and SD III. The mean of E across SDs negatively correlated with GDD ≥ 5°C ($P \leq 0.05$) and GDD ≥ 10°C ($P \leq 0.01$) for variety 'Gustav'. The mean of gs across varieties positively correlated with relative air humidity for all SDs ($P \leq 0.05$ and $P \leq 0.01$) and, averaged across SDs, gs correlated ($P \leq 0.01$) with relative air humidity for varieties 'Barke' and 'Gustav'. Averaged across varieties, gs negatively correlated with sunshine duration ($P \leq 0.01$), GDD ≥ 5°C ($P \leq 0.05$) and GDD ≥ 10°C ($P \leq 0.01$) in SD III and positively correlated ($P \leq 0.01$) with precipitation in SD II and SD III. The positive correlation between the mean of gs across SDs and precipitation was established for 'Barke' and 'Gustav'. The mean of WUE*i* both across varieties and SDs negatively correlated ($P \leq 0.01$) with all meteorological factors, except for mean air temperature. Conflicting data has been obtained by Evrendilek et al. (2008), who detected positive and strong correlation between air temperature and both A and E ($P < 0.001$) of wheat. Takai et al. (2010) have reported that the ambient temperature determines leaf temperature. Some data indicates that canopy temperature was closely correlated with gs ($r = -0.93$, $P < 0.01$) and A ($r = -0.91$, $P < 0.01$).

As presented in the correlation matrix, mean of parameters across both varieties and SDs showed a close concordance in terms of the direction and shape of the relationship among the measured variables (Table 8). The matrix of correlation coefficients revealed that A positively and significantly ($P < 0.01$) correlated with E and WUE*i* in all SDs and for all varieties, while there was a trend for a negative correlation with gs ($P > 0.05$). A negative correlation was detected both averaged across varieties and averaged across SD, between E and WUE*i*, the relationship was significant in SD I ($P < 0.01$) and SD III ($P < 0.05$) and for varieties 'Aura DS' ($P < 0.01$) and 'Barke' ($P < 0.01$). E with gs correlated positively, but the correlation was significant in 50 % for all the tested cases.

Table 8. Correlation matrix of spring barley physiological parameters (2008–2009)

		A µmol CO_2 m^{-2} s^{-1}	E mmol H_2O m^{-2} s^{-1}	gs mol m^{-2} s^{-1}
		Mean across varieties		
SD I	E	0.400**	–	
	gs	0.011	0.170	–
	WUE*i*	0.437**	−0.334**	−0.081
SD II	E	0.598**	–	
	gs	−0.054	0.124	–
	WUE*i*	0.624**	−0.135	−0.106
SD III	E	0.475**	–	
	gs	0.143	0.433**	–
	WUE*i*	0.511**	−0.255*	−0.139
		Mean across SDs		
'Aura DS'	E	0.338**	–	
	gs	−0.085	0.317**	–
	WUE*i*	0.665**	−0.395**	−0.240*
'Barke'	E	0.347**	–	
	gs	−0.038	0.333**	–
	WUE*i*	0.507**	−0.333**	−0.174
'Gustav'	E	0.693**	–	
	gs	0.044	0.095	–
	WUE*i*	0.388**	−0.150	−0.024

Note. A – photosynthetic rate, E – transpiration rate, gs – stomatal conductance, WUE*i* – instantaneous water use efficiency, SD – stand density; *, ** – relationship between indices is significant at $P \le 0.05$ and $P \le 0.01$, respectively.

The results of study with wheat have revealed differences in the shape and strength of correlation between A, E and gs during grain filling phases (Hui et al., 2008). During early grain filling, A was significantly positively correlated with E ($P < 0.01$), while there was a trend for a negative correlation between A and E in both middle and late stage of grain filling. The results of our experiment are in line with the findings of Hui et al. (2008), who reported that there existed inconsistent correlation between A and gs, which did not show statistical significance, and strong significant correlation between E and gs. However, in contrast to our results, Efthimiadou et al. (2010) reported that high significant correlation (0.792, $P < 0.01$ and 0.778, $P < 0.01$) between A and gs was established for maize grown under field conditions The evidence of the present study revealed that mean of A across SDs was not

Table 9. Correlation coefficients of the polynomial correlation between physiological parameters and meteorological factors throughout growing season (2008–2009)

Parameter (y)	Mean across SDs	R	R^2	$F_{fact.}$	Mean across varieties	R	R^2	$F_{fact.}$
A	'Aura DS'	0.722	0.521	15.68**	SD I	0.722	0.521	15.68**
	'Barke'	0.819	0.671	29.38**	SD II	0.835	0.698	33.22**
	'Gustav'	0.858	0.736	40.17**	SD III	0.762	0.580	19.91**
E	'Aura DS'	0.795	0.633	20.37**	SD I	0.761	0.580	16.32**
	'Barke'	0.782	0.611	18.61**	SD II	0.808	0.653	22.29**
	'Gustav'	0.848	0.720	30.37**	SD III	0.772	0.596	17.47**
gs	'Aura DS'	0.458	0.210	3.14**	SD I	0.352	0.124	1.67 ns
	'Barke'	0.583	0.340	6.11**	SD II	0.728	0.529	13.31**
	'Gustav'	0.781	0.610	18.47**	SD III	0.548	0.300	5.08**
WUE*i*	'Aura DS'	0.795	0.633	20.38**	SD I	0.453	0.205	3.06*
	'Barke'	0.498	0.248	3.90**	SD II	0.628	0.394	7.69**
	'Gustav'	0.490	0.240	3.74**	SD III	0.546	0.298	5.01**

Notes. Multi regression equation $y = a + bx_1 + cx_2 + dx_3 + ex_4 + fx_5$, where y – A or E, or gs, or WUE*i*, x_1 – mean air temperature (°C), x_2 – precipitation (mm), x_3 – baseline temperature used for growing degree days (GDD) computation was 5°C , x_4 – baseline temperature used for growing degree days (GDD) computation was 10°C, x_5 – sunshine duration (h). A – photosynthetic rate, E – transpiration rate, gs – stomatal conductance, WUE*i* – instantaneous water use efficiency, SD – stand density; *, ** – relationship between indices is significant at $P \le 0.05$ and $P \le 0.01$, respectively.

correlated with gs for the tested varieties (Table 8). This is in conformity with the data of Anyia and Herzog (2004), who reported that correlation between A and gs was weak and insignificant for 10 genotypes of cowpea under well-watered conditions. However, some other reports do not support the results of this study. In studies with rice, significant correlation between gs and A was obtained for all of seven varieties (r = 0.92, P < 0.001), confirming previous findings that gs is an important determinant of A (Takai et al., 2010).

The multiple linear regression model ($y = a + bx_1 + cx_2 + dx_3 + ex_4 + fx_5$) showed that all physiological parameters of spring barley were intensely influenced by the weather conditions all through the growing season (Table 9). It was found that the interaction of meteorological factors influenced the mean A across SDs by 52.1, 67.1 and 73.6 % for the 'Aura DS', 'Barke' and 'Gustav', respectively. The mean across SDs of E was influenced by weather conditions by 63.3, 61.1 and 72.0 % for 'Aura DS', 'Barke' and 'Gustav', respectively. The influence of meteorological factors on gs was weaker for 'Aura DS' (21.0%) and 'Barke' (34.0%) than for 'Gustav' (61.0%). Meteorological conditions caused 63.3% of WUE*i* data variation for 'Aura DS' and less for other varieties – 24.8% and 24.0% for 'Barke' and 'Gustav', respectively. The correlation coefficients were significant (P < 0.05, P < 0.01) in all the tested cases with one exception.

Conclusion

The varietal and stand density impact on physiological parameters was significant in 50% of the tested cases under dry conditions in May–July period in 2008 and in 75% of the tested cases under dry conditions in May, but very rainy end of June and sufficiently wet July in 2009. The significant influence of growth stage on all physiological parameters was established independently of the moisture regime. The spring barley varieties differed in the tolerance of meteorological factors throughout growing season. The photosynthetic rate and transpiration values were the highest for variety 'Barke' under dry growth conditions and for 'Gustav' under abundant moisture conditions in most of the tested cases. Averaged across varieties, the highest values of photosynthetic rate, transpiration and instantaneous water use efficiency were in medium stand density (400 plants m^{-2}) in most of the cases and the data of the afore-mentioned parameters tended to decrease with increasing stand density. All physiological parameters closely correlated with meteorological factors.

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Agronominių priemonių ir meteorologinių sąlygų įtaka paprastojo miežio (*Hordeum vulgare* L.) fiziologiniams rodikliams

D. Janušauskaitė, O. Auškalnienė, D. Feizienė, V. Feiza

Lietuvos agrarinių ir miškų mokslų centro Žemdirbystės institutas

Santrauka

Yra nedaug duomenų apie pasėlio tankumo įtaką vasarinio miežio (*Hordeum vulgare* L.) fiziologiniams rodikliams, lemiantiems augalų produktyvumą. Tyrimų tikslas – nustatyti vasarinio miežio veislių fiziologinių rodiklių skirtumus esant skirtingam pasėlio tankumui ir įvertinti fiziologinių rodiklių bei meteorologinių sąlygų sąveiką Vidurio Lietuvoje. Auginti trijų veislių miežiai – 'Aura DS', 'Barke' ir 'Gustav', suformuojant skirtingo tankumo pasėlį – 200, 400 ir 600 augalų m^2. Fiziologinių rodiklių vertinimas atliktas keturis kartus per vegetacijos laikotarpį. Veislės ir pasėlio tankumo įtaka fotosintezės grynajam rodikliui (A), transpiracijai (E), žiotelių laidumui (gs) bei vandens eikvojimo efektyvumui (WUE*i*) buvo didesnė esant drėgnoms vegetacijos laikotarpio sąlygoms nei esant sausiems orams. Vasarinio miežio veislės tarpusavyje skyrėsi meteorologinių sąlygų tolerancija per vegetacijos laikotarpį. Veislės 'Barke' miežių fotosintezės grynasis rodiklis buvo didesnis esant sausiems, o veislės 'Gustav' – drėgniems vegetacijos laikotarpio orams. Fiziologinių rodiklių atžvilgiu optimalus buvo 400 augalų m^2 pasėlio tankumas. Pasėlio tankumui didėjant arba mažėjant, lyginant su optimaliu, fotosintetinių rodiklių vertės tendencingai mažėjo daugeliu tirtų atvejų. Meteorologinių veiksnių sąveika turėjo įtakos 52,1, 67,1 bei 73,6 % fotosintezės grynojo rodiklio ir 63,3, 61,1 bei 72,0 % transpiracijos atitinkamai veislių 'Aura DS', 'Barke' ir 'Gustav' miežiams.

Reikšminiai žodžiai: fiziologiniai rodikliai, *Hordeum vulgare*, pasėlio tankumas, veislės.