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Pre- and postheading growth rate and its assocation with grain yield in barley

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Abstract

Understanding pre- and postheading growth rate and dry matter accumulation could provide additional selection criteria for barley breeding programs. The objectives of this study were to evaluate the association of pre- and postheading growth traits with grain yield and other traits in barley. The experiment was carried out at Madison in 1985 and at Arlington in 1985 and 1986. The experimental design was a randomized complete block with four replications. There were significant differences among cultivars in pre- and others in postheading growth rate and dry matter accumulation. Correlation coefficients for growth rate at maturity and postheading growth rate with grain yield were highly significant ($r = 0.93$** and 0.79**, respectively). Cv. 'Robust' was the highest in grain yield and also was high in postheading growth rate and growth rate at maturity. There were significant differences among cultivars in harvest index with 'Morex' lowest and 'Robust' highest. The results showed that differences in pre- and postheading growth traits among barley cultivars are highly associated with yield. Emphasis on these traits could be helpful for grain yield improvement.

Keywords: preheading growth rate, postheading growth rate, *Hordeum vulgare* L., leaf area, harvest index

Introduction

Small grains in the northern US usually need at least 25 to 30 days between heading and physiological maturity to produce high yields. High yields require that dry matter assimilation continues long enough into the season to fill kernels that a plant has formed. Although most small grains accumulate more dry matter before heading than after, favourable conditions should allow the plant to accumulate considerable dry matter after heading (Brinkman & Rho, 1984).

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Dry matter accumulation per unit time is growth rate. Much growth rate studies in small grains have focused on preheading growth (Helsel & Frey, 1981; Jalani et al., 1981; Takeda & Fery, 1976, 1977; Takeda et al., 1979), but several studies have indicated that postheading growth rate should be investigated more thoroughly by small-grain researchers. Postheading growth rate and dry matter accumulation have been positively associated with grain yield in oats (*Avena sativa* L.) (Brinkman & Rho, 1984), and wheat (*Triticum aestivum* L.) (Austin et al., 1980). Conversely, Sherchand & Paulsen (1985) found that postheading dry matter accumulation was not significantly associated with grain yield of wheat cultivars grown in Kansas. Climatic differences, especially after heading, could have contributed to the contrast in results of the studies.

Grain yield is a product of growth rate, growth duration, and harvest index. Harvest index, the ratio of grain yield to total dry matter accumulation at maturity, measures the efficiency of conversion of photosynthate into economic yield (Baker & Gebeyehou, 1982). Several researchers have indicated that harvest index is positively correlated with grain yield in barley (Gymer, 1981; Osman, 1984; Riggs et al., 1981; Thorne, 1958; Watson et al., 1958, 1963; Wych & Ramusson, 1983).

The relationship between leaf area and grain yield in small grains remains variable. Watson (1956) stated that large leaf area, particularly a large flag leaf, is conducive to high grain yield in small grains. Simpson (1968) supported this concept in his studies with wheat. In contrast, Tanner et al. (1966) reported that wheat, oat and barley cultivars that were highest in grain yield had small, upright leaves.

Carbohydrate translocation from leaves in the upper canopy of small grains has been studied in detail. Carbohydrates from flag leaves are translocated almost entirely to the grain, whereas carbohydrates from the second and third leaves are translocated partly to the grain and partly downward (Helsel, 1976). Porter et al. (1950) found that as much as 25 % of the final dry weight in the grain of barley came from assimilation in leaves and sheaths before ear emergence, while 75 % came from photosynthesis above the flag leaf node after ear emergence.

This study was conducted to determine whether there are cultivar differences in pre- and postheading growth rate and dry matter accumulation in barley, and to study the relationships of these traits with grain yield and other agronomic traits.

Materials and methods

Five barley cultivars used in this study were 'Bowers', 'Glenn', 'Hazen', 'Morex' and 'Robust'. These cultivars were chosen because repeated testing showed that they were highly adapted to growing conditions in Wisconsin.

The experiment was conducted at Madison in 1985 and at Arlington in 1985 and 1986. The Arlington soil is a Plano silt loam (typic Argiudoll, fine-silty, mixed, mesic) and the Madison soil is a St. Charles silt loam (typic Hapludalf, fine-silty, mixed, mesic). Fertilizer was incorporated prior to planting at Madison at a rate of 17 kg N ha^{-1}, 15 kg P ha^{-1}, and 84 kg K ha^{-1}. An additional 34 kg N ha^{-1} was topdressed shortly after planting. According to our soil tests, the testing sites at Arlingtron were not fertilized because of the existing high fertility.

The 1985 planting dates were 20 April at Arlington and 27 April at Madison, and the 1986 planting date at Arlington was 13 April. Weeds were controlled by applying bentazon at a rate of 2.3 l ha^{-1} at Arlington and chlorosulfuron at a rate of 35 g ha^{-1} at Madison. In 1985, the systemic fungicide Bayleton was applied shortly after heading at a rate of 420 g ha^{-1} to ensure that leaf rust (*Puccinia hordei* Otth [syn. *P. anomala* Rostr.]) and stem rust (*Puccinia graminis* PERS f. sp. *tritici* Eriks and E. Henn.) did not develop in the barley crop.

The experimental design was a randomized complete block with four replications in each environment. A plot was 7.2 m^2 in area and consisted of 16 rows that were 15 cm apart and 3.0 m in length. At both heading and physiological maturity, 1.5 m^2 was harvested from one-half of each plot and dried at 40 °C for 1 week prior to determining dry weight.

Date for all traits were subjected to analysis of variance. Environmental effects were considered random while cultivar effects were considered fixed. Correlation coefficients between traits were calculated using the Pearson correlation coefficient procedure from the Statistical Analysis System (SAS). Duncan's New Multiple Range Test was used to characterize differences among cultivars.

Results and discussion

There were significant differences among cultivars in growth rate (GRH) and dry matter accumulation (DMAH) at heading (Table 1). 'Glenn' was significantly lower than 'Bowers' in these traits, while 'Hazen', 'Morex' and 'Robust' did not differ from 'Bowers'. 'Bowers' high ranking for these traits could be attributed to the fact that it had larger flag, second, and third leaf areas at heading (Table 1). Positive

Table 1. Growth traits measured at heading for five barley cultivars grown at Madison in 1985 and at Arlington in 1985 and 1986.[1]

Cultivar	Days to heading	DMAH ($g\ m^{-2}$)	GRH ($g\ m^{-2}\ day^{-1}$)	Area of flag leaf	Area of second leaf (cm^2m^{-2})	Area of third leaf	Height at heading (cm)	Culm. weight ($g\ m^{-2}$)
Bowers	56.6a[2]	402.2a	7.1a	2904a	5923a	6297a	78.7a	334a
Blenn	52.8d	319.2b	6.1b	1623b	4214b	4874b	76.7a	346a
Hazen	55.9b	368.1a	6.6ab	1628b	4115b	4769b	76.7a	346a
Morex	54.4c	368.8a	6.8ab	1540b	3899b	4591b	79.5a	375a
Robust	54.7c	369.4a	6.8ab	2031b	4964b	5624ab	78.0a	387a
Means	54.9	365.5	6.7	1945	4623	5231	77.9	358
GXE	**	**	**	ns	ns	ns	*	-

[1] Leaf area was measured at Madison and Arlington, 1985. Culm. weight was measured at Madison, 1985.

[2] Within columns, means not followed by a common letter are significantly different at the 5 % error rate according to Duncan's New Multiple Range Test.

*, ** Significant at the 5 and 1 % error rates, respectively; ns = not significant.

Table 2. Growth traits at maturity, postheading and yield characteristics for five barley cultivars grown at Madison in 1985 and at Arlington in 1985 and 1986.

Cultivars	Days to maturity	DMAM ($g\ m^{-2}$)	GRM ($g\ m^{-2}day^{-1}$)	Height at maturity (cm)	Postheading days	PHDMA ($g\ m^{-2}$)	PHGR ($g\ m^{-2}day^{-1}$)	Grain yield ($g\ m^{-2}$)	Straw yield ($g\ m^{-2}$)	Harvest index (%)	Tillering (number m^{-2})
Bowers	82.6a[1]	638.3a	7.8a	83.6ab	26.0d	236.1ab	9.2ab	325.7ab	312.6a	51.0b	353a
Glenn	81.0c	559.7b	6.9b	83.6ab	28.2a	240.5ab	8.5bc	305.3b	254.3bc	55.0a	325a
Hazen	82.8a	612.9ab	7.4ab	80.8b	26.9c	244.8ab	9.3ab	327.6ab	285.2ab	53.4ab	340a
Morex	81.8b	546.9b	6.7b	85.3ab	27.4bc	178.1b	6.5c	301.0b	245.8c	55.0a	359a
Robust	82.6a	670.2a	8.2a	86.9a	27.9ab	300.8a	11.0a	363.1a	307.1a	54.2ab	336a
Means	82.2	605.6	7.4	84.0	27.3	240.1	8.9	324.5	2810	53.6	344
GXE	**	ns	ns	ns	**	ns	ns	ns	ns	ns	ns

[1]Within columns, means not followed by a common letter are significantly different at the 5 % error rate according to Duncan's New Multiple Range Test.

*, ** Significant at the 5 and 1 % error rates, respectively; ns = not significant.

relationships between leaf area and dry matter accumulation have been reported in wheat, oats, and barley (Watson, 1947; Cannell, 1967).

Differences between cultivars in days of postheading growth duration did not ensure high postheading growth rate (PHGR) and dry matter accumulation (PHDMA). 'Glenn' and 'Robust' had a longer period of postheading growth than 'Bowers', 'Hazen' and 'Morex'. Although 'Robust' and 'Glenn' were similar in duration of postheading growth, 'Robust' was significantly greater than 'Glenn' in PHGR and was 20 % higher in PHDMA. 'Robust' entered postheading growth with significantly more dry matter and 15 % more leaf area than 'Glenn'. This preheading vegetative advantage may have helped 'Robust' to produce more postheading photoassimilates than 'Glenn'.

High dry matter (DMAH), growth rate (GRH), and leaf area at heading (LAH) did not necessarily result in high PHDMA and PHGR. 'Bowers' and 'Robust' illustrate this point very well, as 'Bowers' produced 32.8 g m^{-2} more dry matter at heading than 'Robust' (Table 1), but 'Robust' produced 31.9 g m^{-2} more dry matter at maturity (DMAM) than 'Bowers' (Table 2). This reversal might be attributed to 'Bowers' shorter period of postheading growth duration. A negative relationship between photosynthetic rate and leaf area (Gale et al., 1974) could also have contributed to this reversal. Other factors such as assimilation rate of individual leaves and other tissues capable of photosynthesis may also have contributed to the differences in dry matter acumulation (Monteith, 1965). Similar rankings among cultivars for growth rate at maturity (GRM), PHGR and grain yield were observed (Table 2). The correlation coefficients for GRM and PHGR with grain yield (Table 3) were highly significant ($r = 0.93^{**}$ and 0.79^{**}, respectively). These traits could be useful selection criteria for grain yield improvement in barley breeding programs.

Our results indicate that 'Robust' was highest in grain yield because it was high in dry matter accumulation at maturity (DMAM), due primarily to high PHGR and PHDMA (Table 1). 'Robust' was also high in harvest index (HI). The correlation

Table 3. Pearson correlation coefficients among growth and yield traits of five barley cultivars grown at Madison in 1985 and at Arlington in 1985 and 1986.

	GRH	DMAH	Flag LAH	GRM	DMAM	PHGR	PHDMA	Grain yield	Straw yield	HI
DMAH	0.92**									
Flag LAH	0.47**	0.58**								
GRM	0.48**	0.34**	0.31							
DMAM	0.44**	0.41**	0.34*	0.92**						
PHGR	-0.06	-0.16	-0.02	0.84**	0.78**					
PHDMA	-0.15	-0.23	-0.09	0.75**	0.79**	0.92**				
Grain yield	0.42**	0.28*	0.18	0.93**	0.85**	0.79**	0.72**			
Straw yield	0.32**	0.42**	0.44*	0.64**	0.86**	0.52**	0.63**	0.46**		
HI	-0.01	-0.21	-0.33*	0.15	-0.11	0.17	0.02	0.41**	-0.60**	
Tillering	0.02	0.18	0.00	-0.19	0.07	-0.23	-0.04	-0.16	0.27*	-0.39**

*, ** Significant at the 5 and 1 % error rates, respectively.

coefficient for HI with grain yield was significant (r = 0.41**) (Table 3), which indicates that selection for high HI may improve grain yield. 'Glenn', 'Hazen' and 'Morex' had favourable HI's, but they were not as high as 'Robust' in one or more growth traits, particularly PHGR. 'Bowers' developed a leafy canopy that was high in DMAH, but its postheading duration of growth was shorter than that of 'Robust'. 'Bowers' was 16.4 % and 21.5 % lower than 'Robust' in PHGR and PHDMA, respectively. In addition, 'Bowers' was lower than 'Robust' in HI.

The results of this study indicated that grain yield improvement in barley may be expected if emphasis is placed on growth rate and dry matter accumulation, particularly rate and duration of PHDMA in areas where considerable postheading growth occurs. Barleys with high PHGR and PHDMA, along with favourable HI, should produce high grain yields. Additional studies that compare postheading growth rate and dry matter accumulation with rate and duration of photoassimilatory processes are needed to further elicit why cultivars differ in grain yield. Assimilation and translocation of stem reserves should also be evaluated in these studies.

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