Barley Tiller Response to Plant Density and Ethephon

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ABSTRACT

Ethephon ([2-chloroethyl] phosphonic acid), typically increases barley (*Hordeum vulgare* L.) spikes per square meter by increasing the frequency of late emerging green tillers, resulting in uneven crop maturity. This study was conducted to evaluate barley tiller grain yield and malting quality response to plant density and ethephon, with special reference to late-emerging green tillers. Field studies were conducted at Powell, WY between 1987 and 1989 on a Garland clay loam (fine, mixed, mesic Typic Haplargid). Target plant densities of 150 and 300 plants m^{-2} were established. Ethephon was applied at the Zadoks growth stages (ZGS) of 13, 32, or 39, and one treatment was split-applied at ZGS 32 and 39. Early emerging primary tillers (T1, T2, and T3) and the main shoot contributed 86% of the total grain yield at high plant density vs. 73% at low plant density. In general, increasing plant density resulted in progressively greater differences for kernel plumpness and kernels per spike on the MS, T1, T2, and T3. Ethephon applied at ZGS 39 reduced plant height 6 to 15 cm depending on year. Lodging was reduced by ethephon application, although the lodging level was low in every year of the study. Ethephon did not affect grain yield or protein content, but it often reduced volume mass and kernel plumpness compared to the untreated control. Regardless of ethephon treatment, kernels on late emerging tillers were of lower mass, volume mass, and plumpness than kernels on early emerging tillers. Ethephon applied at ZGS 39 increased the number of late emerging green tillers by 225 spikes m^{-2} compared with the control. These late emerging green tillers contributed 8% to the total grain yield, but produced grain of substandard malting quality.

LODGING in many crops, has been controlled through development of varieties with reduced plant height. Most malting barley varieties are tall in stature, however, and lodging can be a serious constraint to yield and quality. The plant growth regulator, ethephon, is often used for lodging control, especially in intensively managed systems with high N and irrigation inputs. Ethephon allows for faster, more efficient and economical harvesting by preventing late season lodging (1). Under conditions of potential lodging, ethephon application usually protects barley crops from yield reductions (3,11). When lodging does not occur, ethephon application tends to decrease grain yield (9,11,14). In most instances, reduced yield is associated with reduced kernels per spike, lower kernel mass, or both (9). Little information has been reported regarding the effects of ethephon on malting characteristics, such as grain protein content and kernel plumpness.

Tiller production and survival is influenced by plant density (5,6,10). Early-emerging tillers contribute more to grain yield than do tillers that emerge later. This is more prominent at higher plant densities (2). Under normal production conditions, kernel mass and kernels per spike are usually greater on early-emerging tillers than on late-emerging tillers. Differences in kernel mass and kernels per spike for tillers at similar positions are less pronounced as plant density decreases.

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Abbreviations: MS, main shoot; T1, T2, T3, primary tillers in axils of first, second, and third leaves on MS, respectively; TS, tillers mature at harvest; and TX, tillers immature (green) at harvest.

Quite often, ethephon increases spikes per square meter (9,13) by increasing production and survival of late secondary and tertiary tillers which emerge after the application of ethephon. Little is known about the contribution to overall grain yield and malting quality of late emerging green tillers. Likewise, little is known about the effects of ethephon on shoots at specific tiller positions and their subsequent contributions to grain yield and malting quality. The objective of this study was to evaluate barley tiller grain yield and malting quality response to plant density and ethephon, with special reference to late emerging green tillers.

MATERIALS AND METHODS

The study was conducted at Powell, WY from 1987 to 1989. The soil, a Garland clay loam, was prepared for planting by moldboard plowing, roller harrowing twice, and leveling. The soil was fertilized each year in accordance with Univ. of Wyoming soil test recommendations for a grain productivity goal of 5.4 Mg ha^{-1}. 'Klages' spring barley was established in plots 1.8 by 6.7 m using a planter with double disk openers set at a row spacing of 15 cm and a seeding depth of 4 cm. Weeds were controlled with post emergence broadcast application of a mixture of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) and difenzoquat (1,2-dimethyl-3,5-diphenyl-1H-pyrazolim), each applied at the rate of 0.84 kg a.i. ha^{-1} in 187 L water ha^{-1}. Furrow irrigations were performed at the Zadoks growth stages (ZGS) of 00, 32, 45, 71, and 85 which correspond to dry kernel at planting, second node detectable, boot swollen, kernel watery ripe, and soft dough (15). Subsections of each plot, 1.3 by 2.5 m, were harvested using a small plot combine.

In 1987, the experimental design consisted of a randomized complete block with three replications. Ethephon was applied at the rate of 0.28 and 0.56 kg a.i. ha^{-1} in 187 L water ha^{-1}. These rates were applied when Leaf 3 was 50% emerged on the main shoot (ZGS 13), two nodes were detectable (ZGS 32), and the flag leaf collar was visible (ZGS 39). A target plant density of 300 plants m^{-2} was seeded.

In 1988 and 1989, the experimental design consisted of a randomized complete block in a 2 × 5 factorial arrangement with four replications. Factors included plant density and timing of ethephon application. Target plant densities of 150 and 300 plants m^{-2} were seeded. Ethephon was applied at the rate of 0.42 kg a.i. ha^{-1} using 187 L water ha^{-1} at ZGS 13, 32, or 39. An ethephon treatment was split-applied with 0.14 and 0.28 kg a.i. ha^{-1} applied at ZGS 32 and 39. In all years the control treatment received no ethephon.

In 1987, agronomic measurements for each tiller position were determined using 10 randomly selected plants within each plot. In 1988 and 1989, plants within a 1-m section of row were used. Shoots at various tiller positions were identified using colored paper wires. At maturity shoots were separated into six tiller position classifications.

Tillers were classified according to the method of Kirby and Faris (6). The main shoot was designated MS. The primary tillers in the axils of the first, second, and third leaves on the MS were designated T1, T2, and T3. The tiller formed in the axil of the coleoptile, higher order primary tillers, and secondary tillers formed in the axils of the prophyll and leaves on the primary tillers were grouped according to spike maturity. Those tillers which were mature at harvest were designated TS, while those which were still green were designated TX.

A lodging index (9) was calculated using both intensity (the degree to which the crop flattened) and the amount of area affected such that:

$$\text{Lodging index} = \text{intensity score} \times \text{area score} \times 0.2,$$

where intensity score ranges from 1 (erect) to 5 (flat) and area score ranges from 1 (no lodging) to 9 (total lodging). Thus lodging index ranges from 0.2 (no lodging) to 9.0 (total area flat).

Measurements were determined on a combine harvested area, and on a separate hand harvested 1-m row section which was used for tiller position measurements. Kernel mass for the combine harvested area was determined by counting and weighing a 1000-kernel subsample. Kernel mass, by tiller position, was determined by weighing all kernels for that position from the hand harvested 1-m row section and dividing by the number of kernels present on tillers at that position. Spikes per square meter for the combine harvested area was the total number of spikes produced in the 1-m row section. Spikes per square meter, by tiller position, was measured on the 1-m row section for each tiller position group. Kernels per spike, for the combine harvested area, was calculated by dividing the total number of kernels in the 1-m row section by the total number of spikes. Kernels per spike, by tiller position, was calculated by dividing kernel number by spike number for each tiller position group.

Volume mass was determined for each tiller position group by weighing the kernels and measuring their volume using a graduated cylinder. Kernel plumpness was determined on a weight basis by sieving grain on 2.38- by 19.05-mm and 2.18- by 19.05-mm screens. Grain protein content was determined using near infrared spectroscopy (Technicon 400 Infralyzer, Tarrytown, PA) which was calibrated against the Kjeldahl procedure of William (12).

Separate analysis of variance was calculated for data collected from combine harvested areas and hand harvested 1-m row sections. Error variances for each measurement from 1988 and 1989 analyses were tested using Bartlett's test for homogeneity of variances (7). All measurement variances were homogeneous between years, and an analysis across years was performed. Since tiller position cannot be randomized, conservative degrees of freedom were used to test the significance of tiller position variation (7). Each source of variation involving tiller position was divided by the source having the fewest degrees of freedom. Treatment mean comparisons were made using least significant difference when *F* values were significant ($P \leq 0.05$) using conservative degrees of freedom.

RESULTS AND DISCUSSION

Combine Harvested Areas

All ethephon treatments produced malting barley of an acceptable market grade (Table 1). Ethephon reduced plant height by 6 to 15 cm depending on year. Less reduction in plant height was observed in ethephon treatments applied early in crop development. Little or no lodging was observed in the years during which these experiments were conducted. However, when lodging occurred, it was reduced by ethephon application. Averaged across years, ethephon applied at ZGS 39 increased spikes per square meter from 890 to 1130, decreased kernel mass slightly from 43 to 42 mg, and decreased kernels per spike from 19 to 15 (derived from Table 1). In two of 3 yr, ethephon applied at ZGS 39 or 32+39 decreased volume mass and kernel plumpness. On a combine harvested area basis, grain yield and protein content were not affected by ethephon.

Plant density did not affect plant height, lodging index, grain yield, protein content, volume mass, or kernel plumpness in combine harvested areas (data not shown). In 1989, higher plant density increased spikes per square meter from 890 to 1010, decreased kernel mass from 43 to 42 mg, and decreased kernels per spike from 20 to 18.

For the combine harvested areas, results similar to those of this study have been reported in other studies (3,9), in that: (i) ethephon reduced plant height and lodging, (ii) little change was observed between ethephon treated and untreated plots for grain yield and protein content, (iii) ethephon slightly decreased volume mass and kernel plumpness (two of 3 yr in our study), (iv) ethephon tended to decrease kernel mass and kernels per spike, and (v) ethephon usually increased spikes per square meter.

Hand Harvested One-Meter Row Sections

Results from 1988 and 1989 for the hand harvested 1-m row sections were analyzed across years (Table 2). Significant effects due to year and year-interaction were observed. In general, plant density had a greater effect on most agronomic measurements during 1989 compared to 1988, while ethephon application timing had a greater effect during 1988 compared to 1989. Growing conditions during 1988 had higher than normal average air temperatures from ZGS 31 through 75 (one node detectable through medium milk). An intense, hard rain at plant emergence produced a soil crust that decreased the target densities of 150 and 300 plants per square meter to actual plant densities of 127 and 213 plants per square meter. In 1989, actual plant densities were 152 and 295 plants per square meter.

Plant density significantly affected kernel plumpness, kernel mass, spikes per square meter, and kernels per spike (Table 2). Likewise, ethephon application timing significantly affected these same characteristics

Table 1. Agronomic response to ethephon of Klages barley grown at Powell, WY. Data are based on a combine harvested plot area. Values for 1988 and 1989 are averaged across plant density.

Ethephon application		Plant height	Lodging index	Grain yield	Grain protein	Volume mass	Kernel plumpness		Kernel mass	Spike density	Kernel density
Timing	Rate						2.38	2.18			
Zadoks	kg ha^{-1}	cm		Mg ha^{-1}	g kg^{-1}	g L^{-1}	% above		mg	no. m^{-2}	no. spike^{-1}
					1987						
–	0.00	83	1.0	6.9	104	808	96	99	45	940	18
13	0.28	79	0.7	6.0	103	809	95	99	46	1090	16
13	0.56	78	0.4	6.1	103	814	96	99	46	1100	18
32	0.28	77	0.2	7.1	100	803	92	98	43	990	17
32	0.56	76	0.2	5.9	91	801	90	98	42	1120	18
39	0.28	74	0.2	5.6	110	808	94	99	45	1290	17
39	0.56	72	0.2	5.8	114	791	87	95	41	1320	14
LSD (0.05)		5	NS	NS	NS	NS	2	2	2	NS	2
					1988						
–	0.00	64	2.9	4.3	126	765	86	97	41	870	19
13	0.42	63	1.0	5.0	119	767	83	96	40	880	18
32	0.42	60	0.9	5.4	119	733	80	96	39	1230	16
32+39	0.14+0.28	58	0.2	4.5	131	726	83	96	41	1070	15
39	0.42	58	0.2	4.4	137	721	89	97	41	990	14
LSD (0.05)		5	0.9	NS	NS	21	NS	NS	NS	220	1
					1989						
–	0.00	82	0.2	6.4	125	829	95	99	44	870	20
13	0.42	80	0.2	7.0	117	825	91	98	41	890	21
32	0.42	80	0.2	6.8	126	825	94	97	43	880	20
32+39	0.14+0.28	72	0.2	6.4	119	816	91	96	42	1030	18
39	0.42	67	0.2	6.3	127	806	91	97	43	1080	15
LSD (0.05)		3	NS	NS	NS	14	3	1	1	120	1

Table 2. Mean squares from analysis of variance of agronomic characteristics for Klages barley tillers grown at Powell, WY during 1988 and 1989. Data are based on hand harvested 1-m row sections.

Source	df	Grain yield	Grain protein	Volume mass	Kernel plumpness		Kernel mass	Spike density	Kernel density
					2.38	2.18			
		Mg ha^{-1}	g kg^{-1}	g L^{-1}	% above screen		mg	no. m^{-2}	no. spike^{-1}
Year (Y)	1	4.3	1	290 000*	7300*	20	878**	11400	540**
error	6	0.9	111	40 000	900	110	41	14200	40
Plant Density (D)	1	0.1	10	0	3500**	470*	606**	52000**	582**
Y × D	1	0.4	46	34 000*	1500	480*	389**	100	164**
Ethephon (E)	4	0.6	59**	4 000	2900*	370**	112**	23700**	86**
Y × E	4	0.1	41*	36 000**	1600*	510**	99**	19000**	4
D × E	4	0.4	34	14 000	100	160	16	12700	13
Y × D × E	4	0.5	16	10 000	600	360*	12	12100	18
error	54	0.3	16	7 000	500	100	19	5000	10
Tiller position (T)	5 (1)†	27.6**	12**	287 000**	46900**	16090**	2214**	153400**	2353**
Y × T	5 (1)	1.5**	7**	32 000**	2000**	970**	109**	61700**	4
D × T	5 (1)	5.2**	5*	1 000	800**	50	10	80500**	11**
Y × D × T	5 (1)	1.5**	2	13 000*	1100**	70	11	23500**	4
E × T	20 (4)	0.4**	3**	6 000	900**	690**	27**	39500**	8**
Y × E × T	20 (4)	0.3*	2	27 000**	100	200	12	9300**	6**
D × E × T	20 (4)	0.1	1	9 000	100	120	9	4400	2
Y × D × E × T	20 (4)	0.2	0	4 000	200	200	11	6600*	4
error	300 (60)	0.1	1	4 000	100	80	5	2400	2

† Conservative degrees of freedom.

*,** Significant at the 0.05 and 0.01 probability levels.

as well as grain protein content. There were no significant interactions between plant density and ethephon application ($D \times E$) for any agronomic characteristic.

For most measurements, the sources of greatest variation in the analysis across years were observed for tiller position, and treatment interactions with tiller position (Table 2). Significant interactions were observed between plant density and tiller position ($D \times T$) for grain yield, protein content, kernel plumpness, spikes per square meter, and kernels per spike. Similarly, significant interactions between ethephon application timing and tiller position ($E \times T$) were observed for these same measurements and kernel mass. No significant $D \times E \times T$ interactions were observed for any agronomic measurement.

In all years and treatments, a hierarchial relationship among spikes within a plant was observed for every agronomic measurement (Tables 3 and 4). The MS had greater grain yield, protein content, volume

Table 3. Agronomic response to plant density of Klages barley tillers grown at Powell, WY from 1988 and 1989. Data are based on hand harvested 1-m row sections. Values are averaged across year and ethephon treatment.

Actual plant density	Tiller position	Grain yield	Grain protein	Volume mass	Kernel plumpness 2.38	Kernel plumpness 2.18	Kernel mass	Spike density	Kernel density
no. m^{-2}		Mg ha^{-1}	g kg^{-1}	g L^{-1}	—— % above screen ——		mg	no. m^{-2}	no. spike^{-1}
				1988					
139	MS	1.6	125	675	91	99	45	155	23
	T1	1.3	122	669	88	98	44	144	21
	T2	1.1	120	662	84	97	42	133	20
	T3	0.9	118	649	80	96	41	116	19
	TS	1.6	121	653	69	93	38	256	16
	TX	0.2	122	521	23	64	30	113	7
254	MS	2.3	120	679	89	98	43	250	21
	T1	1.7	120	673	84	98	41	213	19
	T2	1.3	113	670	79	96	40	178	18
	T3	0.8	112	650	72	95	38	126	16
	TS	0.8	117	644	54	89	35	175	13
	TX	0.2	130	516	27	60	29	100	6
LSD (0.05)†		0.2	6	NS	7	NS	NS	31	1
LSD (0.05)‡		0.2	12	NS	8	NS	NS	33	1

† For comparison among tiller positions for the same plant density treatment.
‡ For comparison among tiller positions for different plant density treatments.

Table 4. Agronomic response to ethephon of Klages barley tillers grown at Powell, WY during 1988 and 1989. Data are based on hand harvested 1-m row sections. Values are averaged across year and plant density.

Ethephon application Timing	Ethephon application Rate	Tiller position	Grain yield	Grain protein	Volume mass	Kernel plumpness 2.38	Kernel plumpness 2.18	Kernel mass	Spike density	Kernel density
Zadoks	kg ha^{-1}		Mg ha^{-1}	g kg^{-1}	g L^{-1}	—— % above screen ——		mg	no. m^{-2}	no. spike^{-1}
–	0.00	MS	2.2	120	685	93	99	46	208	24
		T1	1.6	117	666	87	98	43	181	20
		T2	1.3	111	664	82	97	42	158	20
		T3	0.9	107	660	77	95	41	122	18
		TS	1.1	109	641	66	91	38	175	15
		TX	0.1	135	456	52	75	33	25	6
13	0.42	MS	1.9	114	681	88	99	43	197	23
		T1	1.6	112	676	83	98	42	182	21
		T2	1.3	106	670	79	96	41	164	20
		T3	1.0	107	648	72	94	39	134	18
		TS	1.1	109	681	57	88	36	188	15
		TX	0.1	111	512	29	79	30	17	8
32	0.42	MS	2.0	120	681	85	98	42	216	22
		T1	1.7	118	669	79	97	41	198	20
		T2	1.3	117	671	74	96	40	174	19
		T3	0.9	112	664	68	94	39	134	18
		TS	1.4	120	627	51	87	34	277	14
		TX	0.1	122	531	17	60	31	55	7
32+39	0.14+0.28	MS	1.8	130	670	88	98	43	196	21
		T1	1.4	130	660	87	98	43	164	20
		T2	1.2	124	666	83	97	41	145	19
		T3	0.8	124	630	78	97	40	109	18
		TS	1.4	131	639	63	93	37	251	15
		TX	0.4	129	550	13	48	27	187	7
39	0.42	MS	1.8	128	670	96	99	45	195	21
		T1	1.3	128	684	94	99	44	166	18
		T2	0.9	126	660	89	98	43	135	16
		T3	0.6	125	645	85	97	41	103	15
		TS	1.0	128	654	70	95	38	187	13
		TX	0.5	133	544	13	46	27	249	6
LSD (0.05)†			0.3	10	NS	10	9	2	49	1
LSD (0.05)‡			0.4	19	NS	13	9	3	53	2

† For comparison among tiller positions for the same ethephon treatment.
‡ For comparison among tiller positions for different ethephon treatments.

mass, kernel plumpness, kernel mass, spikes per square meter, and kernels per spike than any of the tiller positions. Of the tillers, T1 had the highest values for these parameters, followed by T2 and T3. The TS and TX groups were composed of miscellaneous tillers from numerous positions of unidentified origin, and thus, were not considered in the hierarchy.

Averaged across years, the MS, T1, T2, and T3 contributed 86% of the total grain yield when the plant density was high (derived for Table 3). At low plant densities, 73% of the yield was produced by these spikes. In 1988, no interaction was observed between plant density and tiller position for any agronomic measurements except grain yield (data not shown). In 1989, significant interactions were observed between plant density and tiller position for grain yield, kernel plumpness, kernel mass, spikes per square meter, and kernels per spike. In general, increasing plant density resulted in progressively greater differences for kernel plumpness and kernels per spike on the MS, T1, T2, and T3 (Table 3). For example, as plant density increased, kernel plumpness decreased slightly on the MS (from 91 to 89%), while T3 kernel plumpness decreased to a greater extent (from 80 to 72%). Conversely, increasing plant density resulted in progressively smaller differences for grain yield and spikes per square meter on the MS, T1, T2, and T3. Grain protein content was greater at all tiller positions at low plant density, with the exception of TX.

The influence of plant density on tiller characteristics was similar to results of Cannell (2), in that: (i) at high plant densities, early emerging tillers contributed relatively more to yield than at low plant densities where late emerging primary and secondary tillers contributed proportionately more, and (ii) kernels produced on higher order primary and secondary tillers usually had lower kernel plumpness and kernel mass. Interestingly our data indicated that grain protein content was lower on late emerging tillers (except TX) indicating that competition for N between tillers may have occurred (8). This observation may have implications in breeding of malting varieties where low grain protein content is an important trait.

Ethephon applied at ZGS 39 or 32+39 decreased grain yield on the MS, T1, T2, and T3 compared to these same tiller positions in the control (Table 4). Decreases in the yield of these shoots were compensated by grain yield increases on TS and TX. Ethephon decreased kernel plumpness and kernel mass on TS and TX to a greater extent when applied at ZGS 32, 39, or 32+39. Compared to the control, ethephon applied at ZGS 39 or 32+39 decreased kernels per spike on the main shoot, but not on late emerging tillers. Ethephon applied at ZGS 39 and 32+39 increased spikes per square meter to a greater extent for TX than for shoots at other tiller positions. Volume mass decreased with higher order tillers.

Ethephon applied at ZGS 39 and 32+39 did not increase tiller survival of tillers at the MS, T1, T2, and T3 positions (data not shown). In fact, ethephon tended to decrease spikes per square meter at these positions (Table 4).

In general, most currently grown malting barley varieties are tall in stature, and lodging is more of a problem than in small grains where breeding efforts have reduced plant stature. Ethephon is usually applied between the crop growth stages of flag leaf just visible (ZGS 37) and swollen boot (ZGS 45). By this time in crop development all of the potentially developing florets in the apex have differentiated (4), and tillers which die prematurely are normally in the final stages of senescence (10). Thus spikes per square meter and potential kernels per spike have theoretically been determined by the time ethephon is usually applied.

Under control conditions, shoots in the late emerging TX group contributed 1% of the total grain yield compared to 31, 22, 18, 13, and 15% contributed by the MS, T1, T2, T3, and TS (derived from Table 4). However, grain yield contribution by tiller position was greatly affected by plant density (Table 3) and ethephon (Table 4). Ethephon applied at ZGS 39 increased spikes per square meter with most of the increase attributable to shoots of the TX group (Table 4). TX spikes per square meter increased with ethephon application on ZGS 39 from 25 to 249 spikes per square meter, which contributed 8% to the total grain yield. Regardless of ethephon treatment, kernels produced on TX spikes were of substandard grain quality for such malting characteristics as grain protein content, kernel plumpness, and kernel mass. Grain protein content decreased with higher order tillers, however, it sometimes increased for TS and usually for TX, especially with ethephon application at ZGS 32, 39, and 32+39. The volume mass of grain on TX shoots was lower than that of MS, T1, T2, T3, and TS. Kernel plumpness, kernel mass, and kernels per spike decreased on TS and TX. Spikes per square meter was greatest for the MS, followed by T1, T2, and T3. Secondary tillers and other late emerging tillers were more numerous than primary tillers because more tiller positions are included in the group.

In conclusion (i) ethephon is a successful anti-lodging tool, (ii) ethephon application and the subsequent development of late emerging green tillers does pose a problem for growers that direct-combine since crop maturity is uneven, (iii) swathing should take place when the grain on primary tillers is physiologically mature, or shattering losses may occur, (iv) the more numerous late emerging spikes commonly observed following ethephon application do not contribute significantly to overall grain yield and are usually of substandard malting quality.

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