Planting Date and Nitrogen Rate Effects on Spring Malting Barley

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ABSTRACT

Planting date (*D*) and N fertilizer have been shown to significantly increase spring malting barley (*Hordeum vulgare* L.) grain yield and protein when grown under dryland production systems where water is limiting. This study was conducted to determine *D* and N rate effects on grain yield, grain protein, kernel plumpness and yield components of spring malting barley grown under a production system that minimized crop water stress. Between 1984 and 1988, 'Klages' barley was planted at 2-wk intervals between 15 April and 19 May (expressed as days from 1 January) at Powell, WY on a Garland clay loam (fine, mixed, mesic, Typic Haplargid). Ammonium nitrate was applied at rates of 0, 67, 134, and 202 kg N ha^{-1}. Early planting increased kernel weight 14% and kernel density 16% compared to late planting; spike density was not affected. Increasing N from 0 to 202 kg N ha^{-1} increased spike density 39% and kernel density 63%; kernel weight was not affected. Grain yield decreased from 4.7 to 4.0 Mg ha^{-1} with later planting date and increased from 3.4 to 4.9 Mg ha^{-1} as N rate increased from 0 to 202 kg N ha^{-1} [Grain yield (Mg ha^{-1}) = 6.92 − 0.027(*D*) + 0.007(N); R^2 = 0.89, significant at P = 0.01]. Grain protein was unaffected by *D* and increased from 102 to 121 g kg^{-1} as N rate increased from 0 to 202 kg N ha^{-1} [Grain protein (g kg^{-1}) = 127 − 0.194(*D*) + 0.095(N); R^2 = 0.96**]. Kernel plumpness decreased from 97 to 95% with delayed *D* and was unaffected by N rate [Kernel plumpness (%) = 106 − 0.076(*D*) − 0.005(N); R^2 = 0.80**]. Spring barley grain yield and kernel plumpness response to *D* and N rate for furrow irrigated cropping was similar to responses for dryland cropping. However, contrary to dryland results, grain protein was not affected by *D* when grown with minimum water stress.**

PROCESSORS of malting barley are concerned about the effects of grower management factors on grain protein and other malting characteristics. Grower management strategies for malting barley production attempt to maximize grain yield and kernel plumpness and minimize grain protein. Often, management strategies which maximize grain yield will not optimize grain protein and malting quality.

Planting date and N fertilizer significantly affect spring barley grain yield, grain protein and kernel plumpness (9,17). Delayed planting decreases barley grain yield and kernel plumpness (12) while increasing grain protein (3,9,17). Insufficient N can reduce grain yield and quality below acceptable levels, while excessive N usually produces undesirable high protein levels (1,14). Increasing fertilizer N rate increases barley grain yield and grain protein usually in a linear or quadratic fashion depending upon initial soil N levels (4,5,6,7,8,10,14,15). Excessive N decreases kernel plumpness (9,14).

The effects of delayed planting on grain yield and quality under dryland cropping systems are attributed to increased environmental stresses, usually water, encountered by later planted crops (2,17). Crop water stress reduces barley grain yield and malting quality (2,13), especially at high N rates (3,11). The irrigated mountain valleys of northwest Wyoming produce malting barley with exceptional grain yield and quality. The barley crop encounters minimal water stress under furrow irrigation where the soil profile is recharged with water four to six times during the cropping season. This study was conducted to determine planting date and N rate effects on grain yield, grain protein, kernel plumpness and yield components of spring malting barley grown under a production system that minimized crop water stress.

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MATERIALS AND METHODS

The study was located at Powell, WY from 1984 to 1988. The soil, a Garland clay loam was characterized and managed as shown in Table 1. Phosphorous fertilizer in the form of triple superphosphate was broadcast in accordance with University of Wyoming soil test recommendations for a grain productivity goal of 5.4 Mg ha^{-1}. Soil tests indicated adequate K levels for the grain productivity goal. The study area was prepared for planting by moldboard plowing, roller harrowing twice and leveling. 'Klages' barley was established in plots 3.4 by 6.1 m using double disk openers set at a row spacing of 150 mm. The seeding depth was 38 mm, and the seeding rate was 112 kg seed ha^{-1}. Four to six furrow irrigations were applied depending on year (Table 1). Weeds were controlled using MCPA [(4-chloro-2-methylphenoxy)acetic acid] and/or bromoxynil (3,5-dibromo-4-hydroxybenzonitrile).

Planting dates were spaced 2 wk apart with three plantings per year (Table 1). For the analysis across years, planting dates were grouped into early (15 April–21 April), mid (3 May–7 May) and late (17 May–22 May) treatments. All regression equations express planting date as days from 1 January. Nitrogen fertilizer was applied as NH_4NO_3 (34% N) at rates of 0, 67, 134, and 202 kg N ha^{-1}.

From 1984 to 1986, each experimental (planting date) unit was established independently in a randomized complete block with four replications of four N fertilizer rates. The three planting dates were randomized in adjacent blocks each year. In 1987 and 1988, the experimental design was four replications of a randomized complete block in a split-split plot design. Main plots were irrigation treatment where normal irrigation consisted of furrow irrigation at planting, jointing, anthesis, and one to three irrigations during grain filling, and cut-off irrigation treatments withheld water following irrigation at crop anthesis; split-plots were planting date; and split-split plots were N rate.

Tillering characteristics and yield components were determined on 1 m of row within each plot. Grain yield was determined on subplots ranging from 2.2 to 6.0 m^2, depending on year. Percentage of plump kernels on a weight basis was determined by sieving grain on a 2.18 by 19.05-mm screen. From 1984 to 1986, grain protein was determined using the Kjeldahl procedure (16). Grain protein in 1987 and 1988 was determined using near infrared spectroscopy (Technicon 400 Infralyzer, Tarrytown, PA) which was calibrated against the Kjeldahl procedure.

Main effects and interactions were partitioned into single degree of freedom orthogonal polynomial contrasts to investigate linear, quadratic and cubic relationships. Regression equations were determined using stepwise regression of

Table 1. Planting dates and soil characteristics of Klages spring barley grown at Powell, WY on a Garland clay loam from 1984 to 1988.

	1984	1985	1986	1987	1988
Planting date					
Early	19 April	19 April	17 April	15 April	21 April
Mid	3 May	7 May	6 May	4 May	5 May
Late	17 May	22 May	19 May	18 May	19 May
Previous crop	*Phaseolus vulgaris* L.	*Sorghum bicolor* L. Moench	*P. vulgaris* L.	*Brassica napus* L.	*Lathyrus tingitanus* L.
Upper soil depth (mm)	0–203	0–229	0–254	0–229	300
Organic matter (g kg^{-1})	11.0	15.0	12.0	10.0	15.0
pH (saturated paste)	7.6	7.6	7.6	7.8	7.8
P (mg kg^{-1})	7	9	14	14	6
K (mg kg^{-1})	182	208	183	162	211
NO_3-N (mg kg^{-1})	23	18	15	2	8
Lower soil depth (mm)	203–406	229–457	254–508	229–610	–
NO_3-N (mg kg^{-1})	5	9	2	4	–
Number of furrow irrigations (normal/cutoff)					
Early	6	5	4	4/2	6/4
Mid	6	5	4	4/2	6/4
Late	6	4	4	4/2	6/4

the main effects. The estimated regression coefficients for all terms were tested for significance, separately and independently, and only those regression terms with significant (P = 0.05) contribution to the variation in the dependent variable were retained.

RESULTS AND DISCUSSION

Years were analyzed as random effects, however, a highly significant year × N rate interaction occurred for grain yield and grain protein (Table 2). A significant year × planting date × N rate interaction was observed for grain yield. Environmental stress can produce different crop responses depending on the stage of crop development when the stress occurs. For example, in 1986, lodging significantly affected crop performance for the early and midplanting dates, while the late planting date was not affected. For these reasons, the effects of planting date and N rate on grain yield, protein and kernel plumpness are discussed for each year as well as across years.

Table 2. Analysis of variance with orthogonal polynomial partitioning of all treatment main effect and interaction sum of squares for grain yield and grain protein of spring Klages barley grown under normal irrigation at Powell, WY from 1984 to 1988.

		Grain yield (Mg ha^{-1})		Grain protein (g kg^{-1})	
Source of variation	df	Mean square	F	Mean square	F
Year (Y)	4	17.24		7 975	
Error *a*	15	1.28		188	
Planting date (D)	2	13.09	7.04*	652	0.78NS
D linear (l)	(1)	24.93	9.41*	1 285	0.90NS
D quadratic (q)	(1)	1.25	1.16NS	19	0.07NS
$Y \times D$	8	1.86		841	
$Y \times D_l$	(4)	2.65		1 427	
$Y \times D_q$	(4)	1.08		255	
Error *b*	30	0.44		82	
N Rate	3	27.26	14.12**	4 117	8.01**
N linear (l)	(1)	75.76	17.83**	12 297	8.29*
N quadratic (q)	(1)	4.84	6.13NS	40	1.11NS
N cubic (c)	(1)	1.19	1.61NS	15	0.68NS
$Y \times N$	12	1.93	6.43**	514	11.68**
$Y \times N_l$	(4)	4.25	14.17**	1 483	33.70**
$Y \times N_q$	(4)	0.79	2.63*	36	0.82NS
$Y \times N_c$	(4)	0.74	2.47*	22	0.50NS
$D \times N$	6	0.81	1.09NS	77	1.71NS
$D_l \times N_l$	(1)	0.94	0.37NS	92	1.06NS
$D_l \times N_q$	(1)	0.18	1.20NS	103	2.58NS
$D_l \times N_c$	(1)	0.03	0.11NS	18	1.29NS
$D_q \times N_l$	(1)	2.00	2.08NS	117	1.30NS
$D_q \times N_q$	(1)	1.49	3.82NS	57	1.97NS
$D_q \times N_c$	(1)	0.23	1.77NS	78	6.00NS
$Y \times D \times N$	24	0.74	2.47**	45	1.02NS
$Y \times D_l \times N_l$	(4)	2.54	8.47**	87	1.98NS
$Y \times D_l \times N_q$	(4)	0.15	0.50NS	40	0.91NS
$Y \times D_l \times N_c$	(4)	0.27	0.90NS	14	0.32NS
$Y \times D_q \times N_l$	(4)	0.96	3.20*	90	2.05NS
$Y \times D_q \times N_q$	(4)	0.39	1.30NS	29	0.66NS
$Y \times D_q \times N_c$	(4)	0.13	0.43NS	13	0.30NS
Error *c*	135	0.31		44	

*,** Significant at the 0.05 and 0.01 probability levels.
NS = nonsignificant.

Table 3. Tillering characteristics and yield components for Klages spring barley grown at Powell, WY during 1987 and 1988. Data are summarized across years for each treatment.

Treatment	Plant density	Tiller density	Tiller† survival	Tiller‡ mortality	Spike density	Kernel weight	Kernel density
	no. m^{-2}		%	no. m^{-2}		mg	no. m^{-2}
Irrigation							
Cutoff	256	970	64	384	586	40	9 100
Normal	256	1 060	66	408	657	40	10 700
LSD (0.05)	NS	80	NS	NS	58	NS	800
Planting date							
Early	220	1 120	63	464	654	42	10 800
Mid	285	990	63	388	606	41	9 500
Late	262	940	69	337	604	37	9 300
LSD (0.05)	24	110	5	82	NS	1	1 000
N rate (kg N ha^{-1})							
0	250	800	68	283	519	40	7 500
67	257	1 010	61	411	603	41	9 200
134	260	1 090	66	443	643	40	10 700
202	255	1 170	66	448	720	40	12 200
LSD (0.05)	NS	90	NS	71	52	NS	800

† Tiller survival = (tiller density/spike density) × 100.
‡ TIller mortality = tiller density − spike density.
NS = nonsignificant.

Yield Components

Plant density was slightly lower for early than for later planting dates (Table 3), because severe soil crusting in May 1988 decreased emergence of the early planting. Cutoff irrigation management decreased tiller, spike, and kernel density, but not plant density, tiller survival, tiller mortality and kernel weight. Earlier planting dates increased kernel weight and kernel density, but not spike density. Later planting dates resulted in fewer tillers at maximum tiller density, thus, fewer tillers senesced prematurely and a greater percentage survived to produce grain. Increasing N rates increased spike density and kernel density; kernel weight was not affected. No significant interactions between planting date and N rate were observed for yield components, except for tiller survival (data not shown). At high N rates, tiller survival increased in later planting dates compared to early planting dates.

Grain Yield

Grain yield averaged 3.9 Mg ha^{-1} with no N fertilizer applied to the soil. Each kg of N applied from 0 to 202 kg N ha^{-1} linearly increased grain yield 0.007 Mg ha^{-1} (Fig. 1a). The grain yield response to applied N was not as great as previously reported (8,10,14,17). Increasing N rate increased grain yield every year except 1984 (Table 4). Soil NO_3 –N was greater in 1984 than in the other years of the study (Table 1).

Grain yield decreased 0.027 Mg ha^{-1} d^{-1} when planted between 20 April and 19 May (Fig. 1a). In every year, grain yield decreased with later planting date (Table 4). The yield decrease with delayed planting was greater than previously reported (3,9,17); however, the yield level of this study was 49 to 71% greater.

Later planting dates decreased grain yield while increasing N rates increased grain yield (Fig. 1a). Significant orthogonal polynomial contrast interactions were observed in 1985 and 1986 and under the cutoff irrigation treatment in 1988 (Table 4). In 1985, the midplanting date yielded less than the early and late-planting dates. Within each N level, grain yield response to planting date decreased quadratically, except for 0 kg N ha^{-1}, which decreased linearly with later planting date. In 1986, lodging confounded results by reducing grain yield in the early and mid-planting dates. Little relationship was observed between planting date and N rate, except for the 0 kg N ha^{-1} treat-

Table 4. Grain yield response and orthogonal polynomial contrasts for planting date and N rate effects on Klages spring barley grown at Powell, WY from 1984 to 1988.

Planting date	N rate	Normal irrigation 1984	1985	1986	1987	1988	Cutoff irrigation 1987	1988
	kg ha^{-1}	Mg ha^{-1}						
Early	0	4.7	2.6	5.2	3.9	3.3	3.7	2.9
	67	4.4	4.0	5.5	5.3	4.0	5.1	3.4
	134	4.8	4.9	5.4	5.1	4.6	5.1	4.4
	202	4.7	5.3	5.8	6.1	5.4	5.5	5.1
Mid	0	3.9	2.4	4.3	3.2	2.8	2.8	2.1
	67	4.1	3.3	6.2	5.0	3.5	3.8	2.9
	134	4.4	3.8	5.3	4.8	4.2	4.1	3.8
	202	4.1	3.9	5.0	4.9	4.9	4.9	4.6
Late	0	3.2	2.4	3.1	2.7	3.1	2.5	2.1
	67	3.2	3.7	5.0	3.6	3.5	2.9	2.3
	134	3.3	4.1	5.8	4.2	4.3	3.3	3.0
	202	3.1	4.5	6.8	4.4	5.2	3.7	3.0
Source		Orthogonal polynomial contrasts						
Planting date (*D*)								
D linear		–	–	–	**	NS	**	*
D quadratic		–	–	–	NS	NS	NS	NS
N rate								
N linear		NS	**	**	**	**	**	**
N quadratic		NS	**	**	†	NS	NS	NS
N cubic		NS	NS	**	NS	NS	NS	NS
D × *N*								
$D_l \times N_l$		NS	NS	**	NS	NS	NS	*
$D_l \times N_q$		NS	NS	NS	NS	NS	NS	NS
$D_l \times N_c$		NS	NS	NS	NS	NS	NS	NS
$D_q \times N_l$		NS	*	**	NS	NS	NS	NS
$D_q \times N_q$		NS	NS	**	NS	NS	NS	NS
$D_q \times N_c$		NS	NS	NS	NS	NS	NS	NS

†, *, ** Significant at the 0.10, 0.05 and 0.01 probability levels.
NS = nonsignificant.

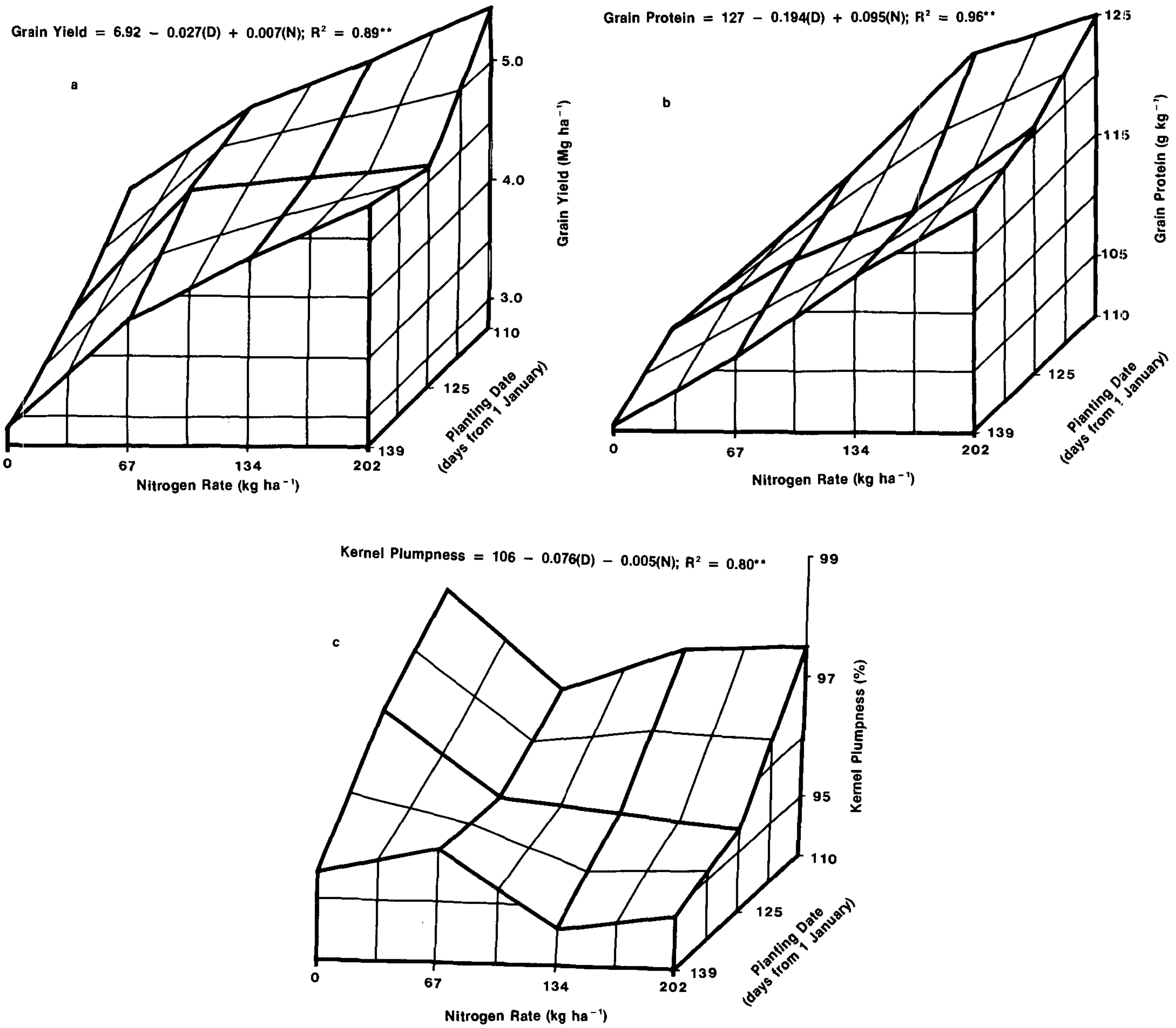

Fig. 1. Planting date (*D*) and N rate effects on a) grain yield, b) grain protein, and c) kernel plumpness of spring barley grown from 1984 to 1988 using normal furrow irrigation. ** indicates significance at $P < 0.01$.

ment where yield decreased linearly with later planting. Yield reductions were greater for early and midplanting dates at 134 and 202 kg N ha^{-1}. In the 1988 cutoff irrigation treatment, grain yield continued to increase linearly as N rate increased for the early and midplanting dates. However, for the late planting date, grain yield response leveled off at 134 kg N ha^{-1}.

Regression analysis for each year indicated that the significant interaction terms contributed little to the variation associated with grain yield (data not shown). In the analysis across years no significant planting date × N rate interaction was observed for grain yield (Table 2).

Grain Protein

Under normal irrigation management, grain protein levels were almost always below 140 g kg^{-1} (Table 5). Grain protein with no fertilizer averaged 103 g kg^{-1}. Each kg N ha^{-1} increased grain protein 0.095 g kg^{-1} (Fig. 1b). In 4 of 5 yr, grain protein increased linearly with increasing N rate (Table 5). In 1984, high soil N supply may have resulted in little grain protein response for the yield level of that cropping season (Table 1).

Planting date did not affect grain protein when analyzed across years (Table 2). A delay in planting date tended to decrease grain protein in 2 of 5 yr (Table 5). In 1984 and 1987, a delay in planting date did not affect grain protein, and in 1988 a delay in planting slightly increased grain protein 8 to 12 g kg^{-1} over that of the early planting date. The cropping season of 1988 had uncharacteristically high air temperatures during grain filling. Cutoff irrigation (after anthesis) treatments increased grain protein in 1987 and 1988, but only slightly (Table 5).

Table 5. Grain protein response and orthogonal polynomial contrasts for planting date and N rate effects on Klages spring barley grown at Powell, WY from 1984 to 1988.

Planting date	N rate	Normal irrigation 1984	1985	1986	1987	1988	Cutoff irrigation 1987	1988
	kg ha^{-1}	g kg^{-1}						
Early	0	114	101	89	95	116	81	123
	67	117	103	110	111	118	99	141
	134	117	113	124	128	128	125	136
	202	114	114	133	130	132	127	143
Mid	0	110	94	83	106	127	99	128
	67	111	94	95	113	135	117	134
	134	112	96	102	120	138	131	145
	202	111	99	123	128	142	139	158
Late	0	114	85	81	98	125	106	128
	67	114	87	87	115	128	127	137
	134	115	91	94	127	137	134	143
	202	116	98	106	138	136	143	148
Source		Orthogonal polynomial contrasts						
Planting date (D)								
D linear		–	–	–	NS	*	*	NS
D quadratic		–	–	–	NS	*	NS	NS
N rate								
N linear		NS	**	**	**	**	**	**
N quadratic		NS	NS	NS	NS	NS	*	NS
N cubic		NS	NS	NS	NS	NS	NS	NS
$D \times N$								
$D_l \times N_l$		NS	NS	**	NS	NS	NS	NS
$D_l \times N_q$		NS	NS	**	NS	NS	NS	NS
$D_l \times N_c$		NS	NS	NS	NS	NS	NS	NS
$D_q \times N_l$		NS	*	NS	†	NS	NS	†
$D_q \times N_q$		NS	NS	*	NS	NS	NS	NS
$D_q \times N_c$		NS	NS	NS	NS	NS	NS	NS

†, *,** Significant at the 0.10, 0.05 and 0.01 probability levels.
NS = nonsignificant.

Table 6. Kernel plumpness response and orthogonal polynomial contrasts for planting date and N rate effects on Klages spring barley grown at Powell, WY from 1984 to 1988.

Planting date	N rate	Normal irrigation 1984	1985	1987	1988	Cutoff irrigation 1987	1988
	kg ha^{-1}	% retained on a 2.18 × 19.05-mm screen					
Early	0	98	98	100	98	100	96
	67	97	95	100	95	100	95
	134	97	96	100	97	100	97
	202	97	95	100	98	100	95
Mid	0	97	96	100	97	100	96
	67	97	90	100	97	100	97
	134	97	88	100	97	100	99
	202	97	88	99	98	99	97
Late	0	92	96	100	94	100	89
	67	93	95	99	96	100	90
	134	92	94	99	93	100	92
	202	93	91	99	97	99	88
Source		Orthogonal polynomial contrasts					
Planting date (D)							
D linear		–	–	*	†	**	*
D quadratic		–	–	NS	NS	NS	*
N rate							
N linear		NS	**	**	†	**	NS
N quadratic		NS	NS	NS	NS	NS	†
N cubic		NS	NS	NS	NS	NS	NS
$D \times N$							
$D_l \times N_l$		NS	NS	**	NS	*	NS
$D_l \times N_q$		NS	NS	NS	NS	NS	NS
$D_l \times N_c$		NS	NS	NS	*	NS	NS
$D_q \times N_l$		NS	*	NS	NS	NS	NS
$D_q \times N_q$		NS	*	NS	NS	NS	NS
$D_q \times N_c$		NS	NS	NS	NS	NS	NS

†, *,** Significant at the 0.10, 0.05 and 0.01 probability levels.

In the analysis across years, no significant planting date × N rate interactions were observed for grain protein (Table 2). Significant orthogonal polynomial contrasts for the planting date × N rate interaction were observed in either normal- or cutoff-irrigation treatments for every year except 1984 (Table 5). No consistent trends were observed within or between years to explain the interactions. Significant interactions were largely due to differences in grain protein response to N rate within a planting date. During 1985, within the early planting date, grain protein increased as N rate increased up to 134 kg N ha^{-1}, then leveled off. Grain protein continued to increase at higher N rates for mid- and late-planting dates. During 1986, a greater increase in grain protein was observed between 0 and 67 kg N ha^{-1} for the early planting date than for the mid- and late-planting dates.

Kernel Plumpness

Kernel plumpness was high in this study (Table 6). Kernel plumpness decreased 0.005% for each kg N ha^{-1} applied (Fig. 1c). Nitrogen rate affected kernel plumpness in three years (Table 6).

Later planting date decreased kernel plumpness 0.076% per day (Fig. 1c). Delayed planting decreased kernel plumpness in 3 yr (Table 6). Across years, delayed planting decreased ($P = 0.10$) kernel plumpness slightly (data not shown). Kernel plumpness was usually greatest on early seeded plots (Table 6). However, the overall difference between early and late seeded plots was only 2% over 29 d, much less than the 4 to 18% previously reported (3,9,17).

Significant polynomial contrast interactions were observed in 1985, 1987 and 1988. Later planting dates decreased kernel plumpness more at high N rate levels. No significant interaction between planting date and N rate was observed for the combined analysis (data not shown).

SUMMARY

The effects of planting date and N rate on spring malting barley grain yield and kernel plumpness were similar to observations made by other workers (3,9,17), with the exception of grain protein. Increasing N rate increased grain yield and protein, and slightly decreased kernel plumpness. Delayed planting of barley between 20 April and 19 May decreased grain yield and slightly lowered kernel plumpness, but grain protein was not affected and even tended to decrease slightly. Previously reported work was performed in environments where the crop encountered water stress at some point during the cropping season, usually during grain filling. Compared to dryland production systems, little water stress occurred in this furrow irrigated cropping system and under these conditions grain protein was not affected by planting date.

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