Fertilization and Agronomic Management for Malt Barley Yield and Quality

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INTRODUCTION

Barley must meet a number of criteria in order to be acceptable for malting (Canada Grains Commission 2004; Canadian Malting Barley Technical Centre 2004). Only certain cultivars are utilized for malting. Two-row cultivars must have 80% plump kernels, 3% thin kernels and a protein concentration of 100 to 125 mg g^{-1}. Six-row cultivars must have 70% plump kernels, 4% thin kernels, and a protein concentration of 105 to 130 mg g^{-1}. Malting barley must also have very low levels of disease, weathering, damage and contamination.

The rate of N fertilizer application is among the most critical decisions for malting barley production due to its large impact on grain yield and quality. In southern Alberta, Bole and Pittman (1980) found that N rates greater than 100 kg N ha^{-1} could be used if available soil water was greater than 150 mm, but only 20 to 50 kg N ha^{-1} could be applied if available soil water was less than 100 mm due to excessive protein concentrations. Kernel size is less responsive to N fertility, but may be reduced with increasing N fertility.

The objective of this study was to determine optimum agronomic practice (cultivar, fertilization, seeding date and seeding rate) for yield and quality of malting barley in southern Alberta.

MATERIALS AND METHODS

Field experiments were completed at 14 locations across southern Alberta from 2001 to 2003 (Table 1). Experiments were conducted at one irrigated location and at least one rainfed location in the Brown, Dark Brown and Black soil zones each year. However, the irrigated site and the site in the Black soil zone were lost in 2002 due to hail.

Experiment 1: The effect of N rate on yield and quality of malting barley was determined for seven barley cultivars. Barley cultivars included the standard 2-row cultivar, Harrington, three other 2-row cultivars (AC Metcalfe, CDC Kendall, and CDC Stratus), and three 6-row cultivars (Excel, B1602 and CDC Sisler). Urea (46-0-0) was banded at rates of 0, 40, 80, 120, and 160 kg N ha^{-1}. A blanket application of triple superphosphate (0-45-0) was applied with the seed at 13.1 kg P ha^{-1}. Plots were arranged in a split plot design with four blocks, barley cultivar as main plot treatment, and N rate as subplot treatment. **Experiment 2:** The effect of P fertilizer rate on yield and quality of malting barley was determined for one 2-row cultivar, AC Metcalfe and one 6-row cultivar, Excel. Monoammonium phosphate (12-51-0) was applied with the seed at rates of 0, 6.5, 13.1 and 19.6 kg P ha^{-1}. **Experiment 3:** The effect of K fertilizer rate on yield and quality of malting barley was determined for AC Metcalfe and Excel. Potassium chloride (0-0-60) was applied with the seed at rates of 0, 25 and 50 kg K ha^{-1}. **Experiment 4:** The effect of S fertilizer

rate on yield and quality of malting barley was determined for AC Metcalfe and Excel. Ammonium sulfate (21-0-0-24) was applied with the seed at rates of 0, 10 and 20 kg S ha^{-1}.
Experiment 5: The effect of seeding date and seeding rate on yield and quality of malting barley was determined for AC Metcalfe and Excel. Three seeding dates were included in this study. The first seeding date was the same as previous experiments and was completed as early as possible. Second and third seeding dates were each delayed by approximately ten days, depending on weather conditions. At each date, barley was seeded at 150, 200, 250, 300, and 350 viable seeds m^{-2}. Data from each site, all sites in each year, and all sites were analyzed with the Proc Mixed procedure of SAS (Release 8.1, SAS Institute Inc., Cary, NC). Sites and blocks were included as random effects and treatments were included as fixed effects. Treatment means were compared with the Tukey-Kramer test.

RESULTS AND DISCUSSION

Weather conditions had a greater impact on malting quality than agronomic practices in this study. For example, none of the agronomic practices tested (cultivar, fertilizer application, seeding date, seeding rate) were sufficient to ensure acceptable malting quality under the extreme drought conditions in 2001. However, agronomic practices had significant effects on malting quality and may be useful to increase the probability of achieving acceptable malting quality under more typical climatic conditions.

Cultivar

Differences in grain yield and quality among the seven cultivars included in this study were modest. Average grain yields were within 3% of the average yield of Harrington, the standard malting barley cultivar in this region over the past 20 years. Based on desired grain protein concentration and kernel size, acceptable malting quality was attainable at 70% of sites for 2-row types and 50% of sites for 6-row types.

Nitrogen fertilizer

The rate of N fertilizer addition was the most influential agronomic variable affecting yield and quality of malting barley in this study. The amount of available N required for maximum grain yield was 33 kg N Mg^{-1} grain.
Protein concentrations were generally within an acceptable range for malting if N fertilizer was applied at rates that were just sufficient for maximum yield.
The variable response of kernel plumpness to N addition is consistent with previous studies that show occasional small negative effects of N addition on kernel size. The proportion of kernels that were plump was reduced by the addition of N fertilizer most strongly at sites with good early-season moisture and late-season drought. At these sites, the negative effect of improved N fertility on kernel plumpness can be attributed to the increase in tiller and spike number during early growth due to N addition, which increased the number of kernels beyond what could be supported during the grain-filling stage.

Prediction of optimum rates of N fertilizer application for malt barley production is difficult due to the uncertainty in estimates of available soil N and N demand. Pre-plant soil NO_3-N is often used to estimate available soil N under semi-arid conditions. Pre-plant soil NO_3-N was generally 20 to 40 kg N ha^{-1} less than unfertilized crop N uptake in Alberta studies, but deviations of more than 50 kg N ha^{-1} were not uncommon. Nitrogen demand varies widely from year to year, depending primarily on available moisture. A rational approach to predict optimum N rate for malting barley could be based on pre-seeding measurements of soil NO_3-N and moisture and historical precipitation records, but deviations of actual from predicted optimum N rates will often be considerable.

Phosphorus, Potassium and Sulphur

Phosphorus fertilizer only provided an economic increase in barley yield at 29% of the sites in this study, in comparison to previous studies from this region where P fertilizer provided small but relatively frequent economic yield increases. A partial explanation for the lack of response in this study is that yield benefits of P application are generally less when a hot, dry summer follows a cool spring, as occurred in 2001 and 2003, due to early-season depletion of soil moisture reserves critical for grain yield formation. An explanation for the absence of P fertilizer benefits in 2002 is unavailable, but might be related to conditions that were conducive for P uptake (moist soil, delayed seeding). The minimal response of grain protein concentration and kernel size can be attributed to the lack of P yield response at most sites. At the few sites with a significant response of kernel plumpness to P application, the proportion of kernels that were plump decreased with P addition. This observation contrasts with the increase in kernel weight observed with P application by Atkins et al. (1955), but is consistent with the hypothesis that early-season P response may deplete soil moisture reserves critical for grain yield formation.

The small or negligible increase in grain yield due to K application in 2002 and 2003 was consistent with previous studies that found little or no yield benefit of K application if exchangeable soil K (0 to 0.15 m) was greater than 200 kg ha^{-1}. Although interesting, the interaction of cultivar and K rate for grain yield only occurred in 2001 and may be an anomaly caused by extreme drought stress. Kernel size did not benefit from application of K fertilizer any more than grain yield.

Although soil SO_4-S was occasionally quite low (<10 kg S ha^{-1}) in the 0- to 0.15-m depth, malting barley did not respond to added S fertilizer. The presence of SO_4-S at lower depths or mineralization from soil organic matter was sufficient to meet crop S requirements, and additional S had no impact on grain yield or quality.

The negligible response of malting barley to the addition of P, K, or S in this study must be interpreted with some caution. Due to large variation in growing conditions, testing at 14 sites over three years may still be insufficient for general conclusions to be reached. For example, the probable effect of weather on P fertilizer response illustrates the importance of basing fertilizer recommendations on long time periods. Land management practices and soil characteristics are also changing (e.g., adoption of conservation tillage, gradual depletion of soil K reserves), and crop responsiveness to nutrient amendments may also change.

Seeding Date

Delayed seeding reduced grain yield at all but one site in this study, consistent with previous reports. The average yield loss of 20% at the latest seeding in this study was less than observed in Minnesota (35%, Beard 1961) and central Alberta (47%, Juskiw and Helms 2003), likely due to the shorter time period between the first and last seeding dates in this study (≈ 3 weeks) than the latter studies (5 to 6 weeks). Yield losses due to late seeding may be less under conditions of good moisture availability. Yield losses were greater in this study under the extreme drought conditions in 2001, when irrigation was discontinued during the grain-filling period.

Plant stand was unaffected by seeding date in previous studies (Duczek and Piening 1982; Juskiw and Helm 2003), but strongly affected by seeding date at most sites in this study. The direction of the impact of seeding dates on stand establishment depended on year: plant stand was reduced by late seeding in 2001 and 2002, but increased in 2003. Weather patterns have an important role on crop emergence, particularly under suboptimal seedbed conditions.

Grain protein concentration was unaffected or slightly increased by delayed seeding in this study, consistent with previous studies that found that grain protein concentration is either unaffected or increased by delayed seeding. The relative impact of seeding date was small: shifts in grain protein concentration were insufficient to alter acceptability of grain for malt at any of the sites tested. Grain protein concentration was controlled primarily by drought stress and N fertility.

Delayed seeding reduced kernel weight or the proportion of kernels that are plump at the 2003 sites in this study, but the opposite pattern was observed at the 2001 sites. A possible explanation for the trends observed in 2001 is that drought stress was earlier and more extreme in 2001 than 2003, which reduced plant stand and possibly kernel density in the late-seeded treatment, which in turn may have improved grain fill.

Seeding Rate

The lowest seeding rate in this study was selected to provide 150 plants m^{-2}, which is close to plant densities that resulted in near maximum yields in southeastern Saskatchewan (136 to 176 plants m^{-2}) (Lafond 1994; Lafond and Derksen 1996). Thus, the modest increase in grain yield with increased seeding rate was not surprising (i.e., up to 500 kg ha^{-1} under irrigation, up to 300 kg ha^{-1} under rainfed conditions). The economic optimum rate of seeding depends on the cost of increased seeding rates relative to the value of harvested crop. Assuming that grain yields must increase four times the increase in seeding rate, optimum seeding rates in this study were about 200 plants m^{-2} under rainfed conditions and 250 plants m^{-2} under irrigated conditions.

High seeding rates were more likely to reduce malt quality than increase it, although effects are mixed and relatively weak. The proportion of kernels that were plump declined by about 10% units under dry conditions and 2.5% units under wet conditions. Countering this effect on malt quality, increased seeding rates reduced grain protein concentration by an average of about 4 mg g^{-1}. A change in protein concentration of this magnitude is likely to have a smaller impact on malt acceptability than the observed changes in kernel size. High seeding rates were not effective in reducing the negative impact of late seeding.

CONCLUSIONS

The rate of N fertilizer application was the most influential agronomic factor controlling yield and quality of malting barley. Maximum grain yields were achieved when available N exceeded 33 kg N Mg^{-1} of potential grain yield, whereas protein concentrations were usually acceptable if available N was between 25 and 40 kg N Mg^{-1} of potential grain yield. Increased N additions reduced kernel size, particularly in a year with moist spring and hot, dry summer conditions, but factors other than N were more important in controlling kernel size. Cultivar differences in N response were negligible. Application of P, K, or S did not affect malt yield or quality in this study, although the lack of fertilizer response, particularly to P, might be due to the weather conditions over the three years of this study.

Seeding delays of ≈20 days reduced grain yields by an average of 20%, with relatively greater yield declines under drought stress. Delayed seeding did not affect or slightly increased grain protein concentration. Kernel size was both increased and decreased by delayed seeding, depending on year. Increased seeding rates from 150 to 350 viable seeds m^{-2} generally provided small yield gains, slight reductions in grain protein concentration and reduced kernel size. The agronomic practices that were most beneficial for malt barley production in southern Alberta were early seeding and application of N fertilizer at rates that were appropriate for expected levels of moisture and available soil N.

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Table 1. Combined statistical analysis of treatment effects (all sites)

Expt. #	Treatment	Plant Stand (plants m^{-2})	Grain yield (kg ha^{-1})	Grain protein (mg g^{-1})	Plump kernels (mg g^{-1})	Thin kernels (mg g^{-1})
1	Cultivar	***(79)[z]	*(57)	**(71)	***(100)	***(100)
	N rate	*(21)	***(93)	***(100)	***(86)	***(86)
	Cult x N	NS(7)	NS(0)	***(0)	*(50)	*(36)
2	P rate	Not determined	NS(0)	NS(0)	NS(21)	NS(7)
3	K rate	Not determined	NS(21)	NS(0)	NS(7)	NS(0)
4	S rate	Not determined	NS(0)	NS(7)	NS(7)	NS(14)
5	Seeding date	***(86)	***(86)	***(64)	*(100)	**(86)
	Seeding rate	***(100)	***(36)	***(29)	***(43)	NS(43)
	Date x Rate	NS(21)	NS(0)	NS(14)	NS(7)	NS(0)

[z] Percentage of sites with significant (P<0.05) treatment effects.

***P<0.001, **P<0.01, *P<0.05, NS not significant.

Table 2. Cultivar effects on plant stand, grain yield and grain quality (Expt. 1)

Cultivar	Rainfed sites			Irrigated sites	
	2001 (n=5)	2002 (n=3)	2003 (n=4)	(n=2)	All sites (n=14)
			Plant stand (plants m^{-2})		
Harrington	153b^{z}	186b	154	170	163bc
AC Metcalfe	142b	176bc	140	165	152c
CDC Kendall	174a	190ab	150	184	172ab
CDC Stratus	152b	181bc	145	179	160c
Excel	96c	165c	150	146	133d
B1602	177a	206a	145	194	176ab
CDC Sisler	145b	180bc	153	187	161bc
			Grain yield (kg ha^{-1})		
Harrington	3167a	4648	4185b	7869ab	4445ab
AC Metcalfe	3033ab	4489	4233ab	8042ab	4402ab
CDC Kendall	3108ab	4816	4256ab	7965ab	4497ab
CDC Stratus	3154a	4750	4290ab	7470b	4443ab
Excel	3056ab	4500	4566a	8490a	4572a
B1602	2804b	4606	4225b	8143ab	4356ab
CDC Sisler	2781b	4719	4218b	7696b	4309b
			Grain protein concentration (mg g^{-1})		
Harrington	131b	92b	113b	104	113c
AC Metcalfe	136ab	95ab	118a	108	118ab
CDC Kendall	140a	97a	112b	109	118a
CDC Stratus	134ab	95ab	113b	108	116bc
Excel	130b	94ab	117ab	104	115bc
B1602	132b	98a	115ab	102	116bc
CDC Sisler	131b	96ab	117ab	105	116bc
			Plump kernels (mg g^{-1})		
Harrington	698a	928ab	752a	901	803a
AC Metcalfe	731a	930ab	767a	943	826a
CDC Kendall	656ab	946a	763a	940	807a
CDC Stratus	644ab	929ab	757a	943	797a
Excel	524bc	873c	547b	904	676b
B1602	394c	890bc	440b	874	599c
CDC Sisler	627ab	917abc	485b	856	698b
			Thin kernels (mg g^{-1})		
Harrington	23c	6	27b	11	16c
AC Metcalfe	20c	5	24b	8	14c
CDC Kendall	27c	5	25b	8	15c
CDC Stratus	25c	5	24b	8	15c
Excel	41b	6	44a	9	22b
B1602	82a	7	60a	13	34a
CDC Sisler	30bc	6	51a	13	22b

^{z}Values within columns followed by the same letter are not significantly different from each other (*P*=0.05, Tukey-Kramer test).