IMPROVING MALTING BARLEY YIELD & QUALITY IN NORTHERN CLIMATES

FINAL REPORT

NORTHERN ONTARIO FARM INNOVATION ALLIANCE

Contents

Executive Summary

The beer brewery industry contributes $13.68 billion to Canada's GDP annually and, as of 2016, supported 149,000 Canadian jobs. Ontario has over 200 craft beer breweries and the Ontario Craft Brewers Association predicts the establishment of more than 500 breweries in Ontario over the next decade. In recent years, craft beer has been the fastest growing segment within the LCBO's beer category, with annual increases of 20-30%. With this growth in craft beer, there is an increased demand for regionally produced malt.

Currently, most malting barley is produced in Western Canada, with Ontario importing over 300,000 tonnes per year. However, with increased demand for Ontario malt, there is strong market potential for Ontario-grown malting barley. The climate in Northern Ontario is somewhat like that of Western Canada and offers a promising opportunity to support further growth in malting barley production. That being said, malting barely must be grown with appropriate management practices to meet all the standards required for brewing, which can be intensive and risky for farmers. Research on variety evaluations and nutrient management techniques will support Ontario growers in accessing these markets.

The Northern Ontario Farm Innovation Alliance coordinated a three-year research project (2018-2021) on "Improving Malting Barley Yield and Quality in Northern Climates", in partnership with the Grain Farmers of Ontario and the Canadian Agricultural Partnership (through the Agricultural Adaptation Council). This was a pan-northern research trial evaluating malting barley varieties and best management practices in different regions across Northern Ontario. The research outcomes were to help Ontario's grain farmers grow malting barley to maximum yield and quality, targeting the domestic market and adding a potential new crop to farmers' rotations.

Trials were conducted at the Ontario Crops Research Centre – Emo (OCRCE), Ontario Crops Research Centre – New Liskeard (OCRCNL), and at the Lakehead University Agricultural Research Station (LUARS) in Thunder Bay.

The work at the three research centres assessed:

1. Ten high yielding varieties of malting barley for yields and quality: Bentley, AAC Synergy, CDC Bow, CDC Kindersley, CDC Fraser, AAC Connect, Lowe, AC Newdale, CDC Copeland and OAC 21.
2. Nitrogen and sulphur management strategies to improve yields while maintaining protein content to acceptable levels. Nitrogen has a major impact on protein levels in the crop, while sulfur levels have been declining in Ontario soils. Both nutrients are likely to increase yields, but the downside is adverse effects on the overall malt quality of the barley. Therefore, varying rates of these nutrients are being tested to determine the best nutrient management plan for malting barley in Northern Ontario. These nutrient tests are being done on CDC Bow. Nitrogen rates of 0, 35, 70, and 105 kg/ha and sulphur rates of 0 and 12 kg/ha were applied in all combinations to the research station plots each year in order to determine their effects on yield and quality. Two nitrogen sources were compared: urea and Environmentally Smart Nitrogen (ESN). ESN is urea wrapped in a biodegradable polymer coating that theoretically only releases the nitrogen when the soil temperature is appropriate for growing, giving crops access to nitrogen when they need it and minimizing nitrogen loss.

The Rural Agri-Innovation Network (RAIN) in Algoma coordinated on-farm trials, which tested the dual-purpose malting barley varieties AC Metcalfe, AC Newdale, and AAC Synergy. These trials are intended to give farmers alternative markets, as the dual-purpose varieties can be used for feed if they fall below malting quality standards.

The ten varieties of malting barley in this trial were measured for yield at each location each year. When averaged across locations and years, AAC Synergy had the highest yield with 5.22 mt/ha, followed by AAC Connect, which had a yield of 4.97 mt/ha.

In terms of malting quality, CDC Kindersley, CDC Fraser, and AAC Synergy were the most promising candidates for cultivation in northern Ontario.

AAC Synergy was also found to be the most successful variety in terms of yield and malt quality in the Algoma on-farm trials. When averaged across on-farm locations and years, AC Metcalfe averaged 0.56 tonnes per hectare, AC Newdale averaged 1.12 tonnes per hectare, and AAC Synergy had the highest yield with 1.52 tonnes per hectare. In terms of malt quality, AC Newdale was deemed acceptable on three of the 10 quality measurements, and was close to acceptability on two others. AC Metcalfe was deemed acceptable on two of the 10 measurements and was close to acceptability on two others as well. AAC Synergy was deemed acceptable on only one of the 10 measurements but was close to acceptability on four others.

Recommendations for nitrogen and sulphur applications to maximize yield were location and year specific and also dependent on the previous crop. The maximum economic N rate (MERN) at Ontario Crops Research Centre Emo and Lakehead University Agricultural Research Station ranged between 45 and 105 kg-N/ha. The MERN at Ontario Crops Research Centre New Liskeard was essentially 0 kg-N/ha, which was likely due to establishing the trials following forage crops.

The blanket recommendation that arose from the nitrogen and sulphur trial for maximizing malt quality in northern Ontario was 0 or 35 kg-N/ha and 12 kg-S/ha. These application rates resulted in the most promising malt quality results seen in this trial.

The two sources of nitrogen (urea and the urea and ESN blend) did not affect either yield or malt quality in any significant manner when compared to each other.

Variety Trial Results

Statistical Methods

Variety trial data was analyzed using a combined analysis of variance model with site, variety, and the site by variety interaction as fixed effects and replicate within site-year, year within site, and variety by year within site interactions as random effects. A heterogeneous trial residual error ANOVA model was used whenever a Likelihood Ratio Test (LRT) identified trial residual error heterogeneity. Also, LRT tests were used to test the significance of random effects (i.e. variety by year within site interaction). Means separation is based on a protected Least Significant Difference test at the 5% level.

Days to heading, days to maturity, and lodging scores often did not vary across replicates (especially at Emo and New Liskeard sites). Test weight and 1000 kernel weights at Lakehead were recorded for only 1 replicate. The analysis of variance for these measurements across all 3 sites were performed using trial variety means using a modification of the ANOVA model described above where the only random effect was the year within site interaction.

Stability regression analysis was conducted to assist with the interpretation of the variety by year within site interactions for grain yield and height. Trial variety data was regressed onto trial average data (trial index) in order to identify differences in variety rankings across sites that are possibly due to trial index and/or larger than average random variability that could not be attributed to trial index. Trial index is represented as the trial average (i.e. average grain yield or height). Varieties with linear responses that have a slope greater than 1 indicate those that tend to increase their response more rapidly than average as trial index increases while those with a slope less than 1 are less responsive than average. Varieties with significant deviations from linear indicate those that have greater than average across trial variability that cannot be explained by trial index.

Definitions

Fixed effect refers to experimental effects under researcher control, for example choice of varieties and perhaps choice of research sites.

Random effect refers to effects not controlled by researchers. For example, years represent weather conditions not under researcher control and replicates represent soil related variability not under researcher control.

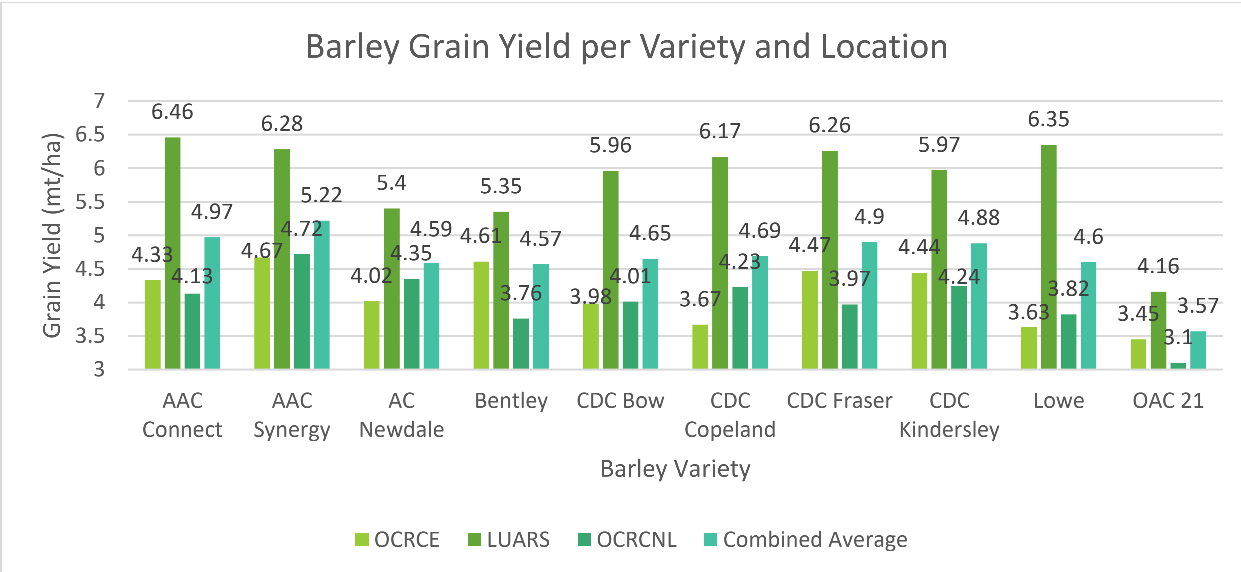
Trial homogeneity (or heterogeneity) refers to a test that indicates if the background variability (residual error) across trials is similar. If not, then the statistical model was modified to address the lack of similar background variability among trials.

The results from the variety trials and the nitrogen and sulphur management trials have been summarized below.

Variety Yield

Across the three years of the trial, AAC Synergy was the variety that consistently had the highest average grain yields with 5.22 tonnes/hectare, while OAC 21 had the lowest with 3.57 tonnes/hectare.

Figure 1



Note. This chart displays the grain yield for each variety of malting barley at each trial location in metric tonnes per hectare. The data is the average of yields across the years of the trial for each location, while the combined average is the average of yields across all locations and all years of the trial (2018-2021). The locations are Ontario Crops Research Centre - Emo (OCRCE), Lakehead University Research Station (LUARS), and Ontario Crops Research Centre - New Liskeard (OCRCNL).

The difference in yield between sites for a given variety could, in some cases, be explained by environmental factors. CDC Copeland and AAC Connect ($P=0.10$) have linear yield responses that are greater than 1. This suggests that these varieties may have a tendency to yield higher than expected in environments with higher yield potential. Since the higher yielding trials tend to be at the LUARS site, this may indicate that these varieties are more specifically adapted to the growing conditions near the Lakehead site compared to Emo or New Liskeard.

Conversely, OAC 21 has a yield response slope that is less than 1 ($P=0.10$). This suggests that OAC 21's yield responsiveness to high yield environments was relatively low compared to many of the other varieties. Also, AC Newdale, Bentley, CDC Bow ($P=0.10$), Lowe CDC Copeland ($P=0.1$), CDC Kindersley and OAC 21 had significant variability that was not explained by linear regression (deviations from linear). This suggests that differences in variety yield rankings across sites for these varieties could not entirely be explained by trial (environment) yield potential. AC Newdale and Bentley had low plant populations at Lakehead in 2018 which partially explains the lack of yield response to yield potential and high yield variability across trials for these varieties.

Straw Yields

Straw yields were similar across sites. Average straw yields across the length of the project at Lakehead ranged from a high of 7.8 tonnes per hectare for CDC Bow to a low of 4.1 tonnes per hectare for OAC 21. Straw yield differences among varieties were not statistically significant at the other sites.

Height

Barley height was statistically similar across sites. Averaged across sites for the length of the trial, the shortest variety was AC Newdale and tallest varieties were Lowe and OAC 21.

Plant and Stem-Tiller Counts

Plant stand counts were statistically similar across sites. CDC Fraser tended to have the largest plant stand counts and Bentley tended to have the smallest. This trend was particularly evident at the Lakehead trials.

Stem-tiller counts differed among sites (*P=1.0*) with the greatest counts at Lakehead and smallest at Emo. Differences among sites is partially due to timing of counts, measurements were taken at heading at Lakehead and within 4 weeks of planting at Emo. Stem-tiller counts differed among varieties with CDC Fraser having the largest stem-tiller counts while OAC 21 the smallest. These trends were particularly evident at the Lakehead and New Liskeard sites.

Grain Protein (New Liskeard only)

Grain protein percentages differed among varieties at New Liskeard. OAC 21 and Lowe had the greatest grain protein percentages, averaging 0.9 to 1.9% greater than the other 8 varieties. Grain protein concentrations did not differ among the other 8 varieties. CDC Copeland and AAC Connect had the numerically smallest grain protein percentage (12.2%).

Test Weights and 1000 Kernel Weights

One thousand kernel weights differed among sites with Lakehead having greater weights (10.2 to 13.8 grams) than New Liskeard and Emo. Across all trials, OAC 21 had the lowest kernel weights averaging between 9.4 – 11.0 grams per 1000 kernels less than AAC Connect, AAC Synergy, CDC Fraser, CDC Bow, and Bentley. The site by variety interaction was significant with the 5 varieties that had the highest overall 1000 kernel weights not consistently having the highest weights within each of the 3 sites. OAC 21, AC Newdale and CDC Kindersley consistently had 1000 kernel weights that were always less than the varieties that had the largest weights within each site.

Test weights tended to differ among sites (*P=10*), with Lakehead test weights averaging 6.5 kilograms per hectoliter more than Emo. Test weight differences among varieties differ only at Emo with CDC Bow, AAC Synergy and CDC Kindersley having the largest test weights and CDC Copeland having the smallest. There was a tendency for a site by variety interaction (*P=0.10*), which was in part due to CDC Copeland not having relatively low test weights at the Lakehead and New Liskeard sites.

Days to Heading and Maturity

Days required for heading and maturity were statistically similar across sites. OAC 21 consistently across all sites required the least number of days to head, heading between 4 and 7 days earlier than other varieties. OAC 21 also tended to be among the earliest varieties to reach maturity.

Lodging

On average, lodging scores did not statistically differ among sites. At trials with some lodging, OAC 21 tended to have the largest lodging scores while Bentley and CDC Bow had the smallest.

Nitrogen and Sulphur Management Trials

Nitrogen rates of 0, 35, 70, and 105 kg/ha and sulphur rates of 0 and 12 kg/ha were applied in all combinations to the research station plots each year in order to determine their effects on yield and quality. Two nitrogen sources were compared: urea and Environmentally Smart Nitrogen (ESN). ESN is urea wrapped in a biodegradable polymer coating that theoretically only releases the nitrogen when the soil temperature is appropriate for growing. ESN is supposed to provide nitrogen to crops when they need it while minimizing nitrogen loss through leaching or run-off.

Ontario Crops Research Centre – New Liskeard Results

2018

In 2018, measurements from New Liskeard showed a generally low response to both urea and urea and ESN mix nitrogen fertilizers. On average, applying nitrogen increased height by 3 centimetres and increase protein content by 0.5%, both of which are of little agronomic significance.

Maturity was generally delayed by about 3 days for higher rates of nitrogen application (70 and 105 kg-N/ha). Maturity generally occurred about 92 days after planting for the lower 0 and 35 kg-N/ha treatments and 95 days for the 70 and 105 kg-N/ha treatments.

Applying 12 kg-S/ha increased average yields by 0.20 tonnes per hectare and stem-tiller number by 81 stems-tillers/m^2. Applying sulphur was also associated with slight decreases (*P=0.10*) in 1000 kernel weight (0.4 g) and test weight (0.5 kg/hl), however these findings are of minor agronomic significance.

Applying 105 kg-N/ha increased grain protein by 0.2% over where 35 kg-N/ha was applied. Highest stem-tiller number was associated with the 70 kg-N/ha rate. A slight reduction in test weight was associated with the 70 kg-N/ha rate (*P=0.10*). These responses are small and of little agronomic significance.

The 2018 trial was essentially non-responsive to nitrogen fertilizer. A significant yield response equation could not be fitted and maximum economic N rate (MERN) for this trial was essentially 0 kg-N/ha and a yield of 4.9 mg/ha.

2019

Due to harvest difficulties, the 2019 nitrogen and sulphur trials in New Liskeard could not be analyzed.

2020

In 2020, the data showed that the rate of nitrogen application again did not significantly affect yield, 1000 kernel weight, plant population, or tiller counts. Test weight measurements decreased by 0.6 kg/hl (*P=0.10*) as nitrogen rate increased from 35 to 105 kg-N/ha. Grain protein concentrations increased with increasing nitrogen rates, averaging 12.7% with no nitrogen application, to 13.1% at the 105 kg-N/ha rate. The source of nitrogen (urea or the urea and ESN blend) did not affect overall 1000 kernel weight, test weight, plant population, or stem-tiller counts. Averaged over sulphur rates, nitrogen source also did not affect yield or grain protein response to nitrogen rates, however, the source of nitrogen did result in slightly different responses depending on the sulphur rate.

When combined with 12 kg-S/ha, increasing urea nitrogen rates resulted in increased yields. However, the opposite occurred when no sulphur was applied, resulting in 0.81 tonnes per hectare higher yield for the 105 kg-N/ha rate with 12 kg-S/ha compared to where no sulphur was applied. Sulphur effects on yield response to urea and ESN nitrogen rates were smaller and not significant. Averaged over nitrogen rates, applying sulphur combined with nitrogen in the form of urea increased yield by 0.30 tonnes per hectare.

Significant grain protein response to sulphur occurred only where 70 kg-N/ha was applied in combination with 12 kg-N/ha. This combination increased protein concentrations by 0.5% where urea was the nitrogen source. However, the opposite occurred with the urea and ESN blend, where a 0.5% reduction was associated with applying sulphur. Averaged over nitrogen rates, applying sulphur increased grain protein concentration by 0.2% when urea was the nitrogen source but decreased grain protein concentration by 0.3% when urea and ESN was the nitrogen source.

Days to heading did not differ among treatments, with treatment heading averages ranging from 56 to 57 days after planting. Days to maturity also was not affected by treatments with averages ranging from 88 to 89.5 days after planting. Applying sulphur generally did not significantly affect 1000 kernel weights, test weights, or tiller number in 2020.

Grain yield response to nitrogen rate was slightly affected by both sulphur and nitrogen source. Grain yield increased linearly where the nitrogen source was urea and 12 kg-S/ha was applied (equation: Yield=4.63 + 0.0058N) with an estimated yield of 5.24 tonnes per hectare at 105 kg-N/ha. The response equation for the urea and ESN blend with 12 kg-S/ha is $4.74+0.0102N-0.00014560N^2$ with yield maximized at 35 kg-N/ha with an estimated yield of 4.92 tonnes per hectare. Significant response equations could not be developed where sulphur was not applied and the maximum economic nitrogen rate (MERN, the most economical rate of nitrogen application) is essentially 0 kg-N/ha with estimated 0 kg-N/ha yields of 4.71 tonnes per hectare where urea was the nitrogen source and 5.06 tonnes per hectare for the urea and ESN blend.

Ontario Crops Research Centre – Emo Results

2018

In 2018, flooding damage severely compromised barley growth and yield. As a consequence this data was discarded.

2019

The 2019 trials showed a significant response to nitrogen rates. The 0 kg-N/ha rate produced the least significant impacts, while the 105 kg-N/ha rate produced the largest impacts, resulting in increased grain yield, straw yield, 1000 kernel weight, test weight, and height. Averaged over the different nitrogen rates, applying nitrogen increased grain yield by 2.27 tonnes per hectare, straw yield by 1.51 tonnes per hectare, 1000 kernel weight by 14.8 grams, test weight by 5.5 kilograms per hectoliter, stem-tiller number by 36 stems-tillers/m^2 and height by 19.1 centimetres. Within nitrogen rates of 35 to 105 kg-

N/ha, applying 105 kg-N/ha increased grain yield by 1.23 tonnes per hectare, straw yield by 1.1 tonnes per hectare, 1000 kernel weight by 5.4 grams, test weight by 2.8 kilograms hectolitre and height by 9.7 cm. Plant population was not affected by nitrogen application and stem-tiller numbers were similar among nitrogen rates of 35 to 105 kg-N/ha. The nitrogen source generally did not affect the responses except for grain yield where the urea and ESN blend produced slightly higher yields at the 35 kg-N/ha rate (0.34 tonnes per hectare, *P=0.10*), with the effect lessening as nitrogen rate increased.

Sulphur affected the nitrogen rate response for straw yield, stem-tiller number, and height. The response to increasing nitrogen rate was greater where sulphur was applied, resulting in straw yield increase of 0.7 tonnes per hectare (16%) and stem-tiller number increase of 49 stems-tillers/m^2 (29%) where 105 kg-N/ha was applied. Straw yield response to sulphur tended to be larger where the nitrogen source was urea only, with yield increases of 0.8 to 0.9 Mg/ha (21%) at the 70 and 105 kg-N/ha rates. On average, sulphur increased straw yields by 0.32 tonnes per hectare, which was mostly due to sulphur application increasing straw yields where 70 or 105 kg-N/ha was applied as urea as well.

Heading occurred 59 days after planting except for the 0-N rate where heading occurred 62 days after planting. Similarly, maturity occurred 91 days after planting where nitrogen was not applied, otherwise maturity occurred 89 days after planting.

The urea and ESN blend attained maximum yield response at an application rate of 89 kg-N/ha with an estimated yield of 4.10 tonnes per hectare. Where urea was the nitrogen source the maximum yield response was attained at an application rate of 140 kg-N/ha with an estimated yield of 4.47 tonnes per hectare. Maximum economic nitrogen rates (MERN) are near 80 kg-N/ha for the urea and ESN blend and at least 105 kg-N/ha for urea.

2020

The 2020 results also showed significant responses to nitrogen rate. Applying nitrogen increased grain and straw yield, 1000 kernel weight, test weight, and plant height. Averaged over nitrogen source and rate treatments, applying nitrogen increased grain yield by 2.59 tonnes per hectare, straw yield by 2.59 tonnes per hectare, 1000 kernel weight by 15.5 grams, test weight by 6.6 kilograms per hectolitre and height by 6.1 cm. Grain and straw yields increased over nitrogen rates, attaining their highest values at the 105 kg-N/ha rate. Test weight, 1000 kernel weights, and plant heights did not significantly differ among the 35, 70, and 105 kg-N/ha rates. Nitrogen treatments did not significantly affect plant population or stem-tiller counts in 2020. The response of any measurement to nitrogen rate was not affected by nitrogen source in 2020.

Heading occurred 62 days after planting except for the plots where 0-N and 35 kg-N/ha were applied as urea, in which heading occurred 65 days after planting. Similarly, maturity occurred 99 days after planting where either nitrogen was not applied or 35 kg-N/ha as urea was applied, otherwise maturity occurred 95 days after planting.

Sulphur increased grain yield on average by 0.35 tonnes per hectare in 2020. This was primarily due to a larger yield response to applied nitrogen with sulphur; yield increased by 0.27 tonnes per hectare without sulphur and 1.01 tonnes per hectare with 12 kg-S/ha as nitrogen rate increased from 35 to 105 kg-N/ha. Sulphur generally did not affect response to applied nitrogen for straw yield, 1000 kernel weight, test weight, plant population, or tiller counts in 2020. For the few occurrences with significant F-tests, the effects were not agronomically significant.

Grain yield response attained its maximum at 51 kg-N/ha applied with an estimated yield of 3.82 tonnes per hectare where sulphur was not applied. Where sulphur was applied the yield response attained its maximum at 80 kg-N/ha with a estimated yield of 4.49 tonnes per hectare. Maximum economic nitrogen rates (MERN) are near 50 kg-N/ha where sulphur was not applied and 75 kg-N/ha where sulphur was applied.

Lakehead University Agricultural Research Station Results

2018

The 2018 trials showed that treatments did not affect days to heading or maturity, which occurred 60 and 103 days after planting respectively.

The urea and ESN nitrogen source slightly increased stem-tiller counts by 24 stems-tillers/m^2 (4%, *P=0.10*) compared to just urea. Otherwise, grain yield, straw yield, plant population, and height were not significantly affected by the source of nitrogen fertilizer. The nitrogen rate by source interactions were all not significant, indicating that response to nitrogen rate was not affected by nitrogen source.

Averaged over all nitrogen rate treatments, applying nitrogen increased grain yield by 1.70 tonnes per hectare, straw yield by 1.07 tonnes per hectare, Stem-tiller number by 86 stems-tillers/m^2, and height by 6.7 cm. Nitrogen application was also associated with higher plant population (34 plants/m^2). Within the nitrogen rates applied (35 to 105 kg-N/ha), applying 105 kg-N/ha increased straw yield by 0.75 tonnes per hectare, stem-tiller number by 52 stems-tillers/m^2, and height by 3.8 cm. Applying 70 kg-N/ha increased grain yield by 0.54 tonnes per hectare compared to where 35 kg-N/ha was applied, but this response was statistically just above the 10% significance threshold (*P=0.1051*).

Grain yield response attained its maximum at 71 kg-N/ha with a yield of 6.78 tonnes per hectare. Maximum economic nitrogen rate (MERN) is near 65 kg-N/ha.

Sulphur application did not affect grain yield, straw yield, plant population, stem-tiller number or height. Sulphur application also did not affect the response to nitrogen for these measurements.

2019

In 2019, treatments did not affect days to maturity, which occurred 97 days after planting.

On average, grain yield, straw yield, plant population, stem-tiller number, and height were not significantly affected by the source of nitrogen fertilizer (urea or urea and ESN blend). Straw yield and stem-tiller number had nitrogen rate by source interactions. Straw yields were more responsive to the rate of urea and ESN blend (2 tonnes per hectare) than to urea alone (0.9 tonnes per hectare). Stem-tiller number increased by 140 stems-tillers/m^2 from 35 to 105 kg-N/ha applied as urea with essentially no response with the urea and ESN blend. Overall, nitrogen source had little impact on barley response to N rate.

Averaged over all nitrogen rate treatments, applying nitrogen increased grain yield by 2.94 tonnes per hectare, straw yield by 2.63 tonnes per hectare, stem-tiller number by 184 stems-tillers/m^2, and height by 21.6 cm. Within the nitrogen rates applied (35 to 105 kg-N/ha), applying 105 kg-N/ha increased grain yield by 1.48 tonnes per hectare, straw yield by 1.31 tonnes per hectare, and height by 11.2 cm. Stem-tiller number was increased by 75 stems-tillers/m^2 when nitrogen rate was increased from 35 to 70 and 105 kg-N/ha (*P=0.10*).

Averaged over nitrogen treatments, sulphur application did not affect grain yield, straw yield, plant population, stem-tiller number, or height. Significant nitrogen application by sulphur interactions suggest that sulphur affected straw yield and stem-tiller number responses to nitrogen application. Generally, the interactions were due to more variability among sulphur rates where nitrogen was not applied. There were a couple of unexpectedly high straw yields where nitrogen was not applied and it is unlikely that the interaction identified an effect of agronomic significance.

Grain yield response attained its maximum at 102 kg-N/ha with a yield of 6.07 tonnes per hectare. Maximum economic nitrogen rate (MERN) is near 95 kg-N/ha.

2020

At LUARS in 2020, the trial had unusually low and variable yields. A few plots did achieve yields exceeding 5 tonnes per hectare, but the majority of plot yields were less than 3 tonnes per hectare. This was likely the result of unusually severe stress conditions which limited barley growth and yield. Treatments did not affect days to heading which occurred 57 days after planting. Similarly, treatments did not affect days to maturity, which occurred 83 days after planting.

Sulphur generally did not affect response to nitrogen rate in 2020. The exception was for straw yield. Increasing sulphur rate increased straw yield averaged over nitrogen treatments by 0.67 tonnes per hectare where urea was applied. Conversely, increasing sulphur rates decreased straw yield by 0.54 tonnes per hectare where the urea and ESN blend was applied.

Applying sulphur was associated with a 0.51 tonnes per hectare yield reduction (*P=0.10*). Otherwise, sulphur application did not affect straw yield, plant height, plant population, or stem-tiller counts in 2020.

Source of nitrogen did not affect grain and straw yield, plant height, or stem-tiller counts in 2020. Averaged over all nitrogen rate treatments, applying nitrogen increased grain yield by 0.98 tonnes per hectare and straw yield by 0.76 tonnes per hectare. Increasing nitrogen rates from 35 to 105 kg-N/ha increased grain yield by about 0.5 Mg/ha (*P=0.10*) and straw yield by 0.4 Mg/ha (*P=0.10*).

Plant population increased by 76 plants/m^2 as nitrogen rate increased from 35 to 105 kg-N/ha. On average, plant population was 57 plants/m^2 greater where the urea and ESN blend was applied. These plant population effects were mainly due to the 105 kg-N/ha of urea and ESN treatment having plant population that averaged 97 to 191 plants/m^2 more than the other nitrogen source by rate treatments. Nitrogen rate or source did not substantially affect plant height or stem-tiller counts in 2020.

Grain yield response attained its maximum at 94 kg-N/ha with a yield of 2.62 metric tonnes per hectare. Maximum economic nitrogen rate (MERN) is near 75 kg-N/ha.

Averaged over all nitrogen treatments, 1000 kernel weight was increased by 3.4 grams by nitrogen application. Increasing nitrogen rate from 35 to 105 kg-N/ha increased 1000 kernel weight by 2.1 grams (P=0.10). Similarly, test weight averaged over all nitrogen treatments was 1.9 kilograms per hectolitre greater than where nitrogen was not applied. Greatest test weight occurred for the 70 kg-N/ha rate, averaging 1.2 kilograms per hectolitre more than where 35 kg-N/ha (*P=0.10*) was applied.

Variety Trial Results Summary

Sulphur was only occasionally associated with slight grain and/or straw yield increases which sometimes occurred only at the higher nitrogen rates. Consistent responses to sulphur application were not identified. The results from these trials support addition of small amounts of sulphur to maximize yields provided it is not an expensive application. It is likely that economically optimal sulphur application would be achieved by adding ammonium sulphate to the nitrogen fertilizer blend.

Lodging, days to heading, and days to maturity were never affected by either nitrogen rate, nitrogen source, or sulphur application.

Nitrogen fertilizer increased grain and straw yields at the Emo and Lakehead sites. Nitrogen also increased 1000 kernel weights and test weights at these sites. Often nitrogen also slightly increased stem-tiller counts and mature plant height. There was generally no significant difference in these responses between the urea and ESN blend and the only-urea nitrogen treatments.

Except for grain protein concentration, nitrogen generally did not affect grain yield and most of the other measured parameters at New Liskeard. Applying 105 kg-N/ha increased grain protein concentrations by about 0.5%.

Maximum economic nitrogen rates (MERN) were site and year specific at the Emo and Lakehead trials, ranging between 45 to 105 kg-N/ha. The economic nitrogen rates at New Liskeard are essentially 0 kg-N/ha, which was likely due to establishing the trials following forage crops.

Barley Quality Analysis

Prior to being accepted for malting, barley goes through two assessments. The first is barley quality assessment. Should the results of the barley quality assessment be acceptable, the malting quality will be tested according to the specifications of the American Society of Brewing Chemists (ASBC). Should those results be acceptable, then the barley can be used for malting. This section addresses some of the criteria for the barley quality assessment. The main factors limiting the acceptability of harvested barley for malt include protein concentration, chitting, and the percentage of plumps.

Protein

The target values for protein in malting barley are between 10 and 13 per cent. If protein levels are too low, it can be problematic for yeast health; if protein levels are too high, there may be issues clearing the beer and an increase in difficulties during both the malting and brewing processes. A deeper explanation of protein is provided below in the malt quality analysis. Most varieties tested in this trial have relatively high protein concentrations but would be acceptable.

Chitting (Pre-harvest sprouting)

Pre-harvest sprouting percentage is an indicator that the germination process has begun in the field before the barley has been cleaned to be malted. Pre-harvest sprouting will result in a low germination energy and can also result in elevated levels of beta-glucan in the malt. Neither of these outcomes are good from a malting or brewing perspective. The majority of samples in this trial have a very high percentage of chitted grains, which is indicative of pre-harvest sprouting, but both Lowe and OAC21 had acceptable numbers. The barley varieties developed in western Canada have a 'hot' enzymatic package, which makes them susceptible to chitting when grown under the higher moisture conditions of eastern Canada. One way to reduce pre-harvest sprout damage is to harvest malt barley at higher moisture levels (16-18%) and use forced air to dry the grain down to a stable storage moisture.

Percentage of Plump Grains

Cleaned grains are passed through a buckwheat riddle to measure the percentage of grains that are greater than 6/64" in diameter. Homogeneity in grain size is very important to ensure an evenness in germination during the malting process. Generally, the percentage of plump grains (those that do not fall through the 6/64" screen) should be greater than 90% in order to make grade. In this trial, Only CDC Fraser and AAC Synergy had 90% plump grains, with CDC Bow close behind with 88%. The rest of the malt varieties do not make grade.

Malt Quality Analysis

After barley quality is assessed, and if the results are acceptable, barley will then be tested for malt quality. Malt quality is measured in a lab using a variety of equipment and standardized methods according to the specifications of the American Society of Brewing Chemists (ASBC). Many of the factors assessed can be affected by barley genotype (variety), management, and environment.

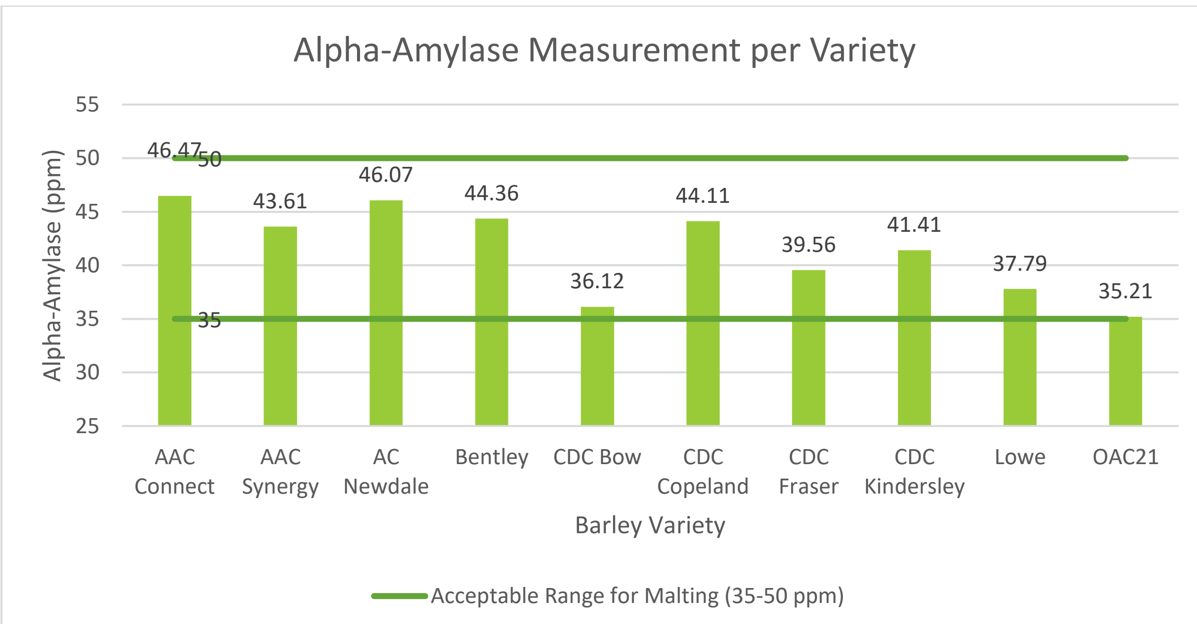
Germination Energy

Germination is measured by soaking grain kernels in water and measuring the percentage of grains that germinate. 95% of the kernels should be germinated within three days. Most of the barley varieties in this trial rated highly for germination and would be suitable for use in a craft malting situation.

Enzyme Activity and Concentration

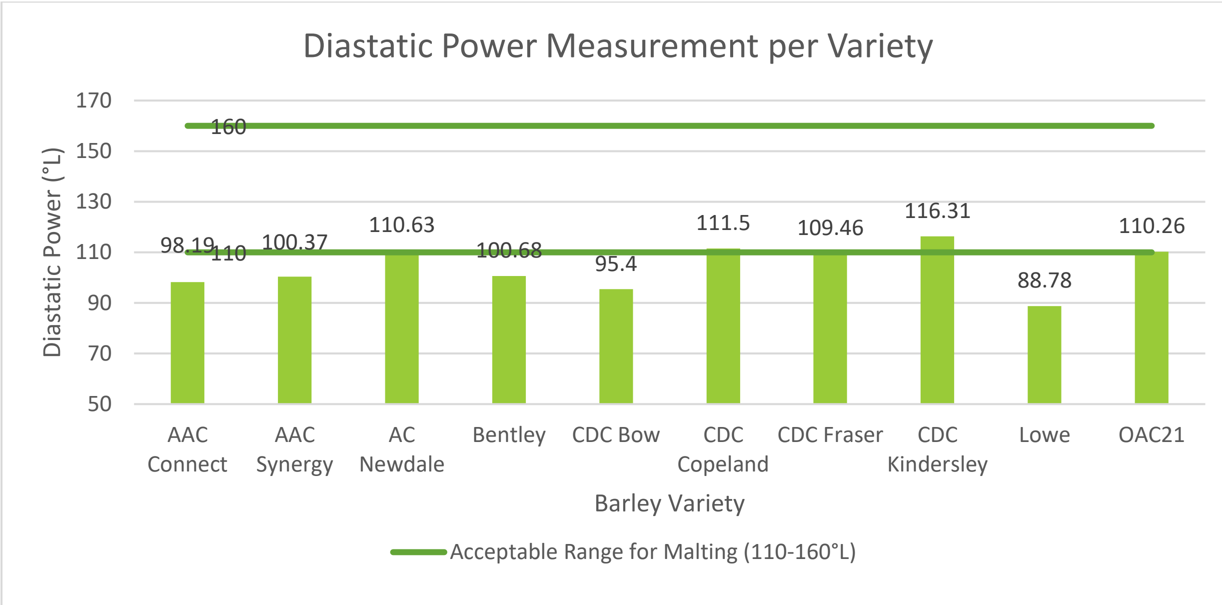
Enzymatic activity is important for both malting and brewing. Alpha-amylase is one of the key enzymes responsible for the degradation of starches to sugars in barley. The concentrations of alpha-amylase should be in the range of 35-50 parts per million to allow for a robust conversion of starch into sugars. Most varieties tested in this trial fell within that range.

Figure 2



Although alpha-amylase is the most important enzyme to the malting and brewing process, it is not the only one. Diastatic power (DP) is a measurement of all starch degrading enzymes, not just alpha-amylase and it is an indication of total amount of enzymes available to convert all starches to sugar. Higher DP values are preferred, especially if brewers will be brewing with adjuncts such as corn or rice, which do not have enough enzymes for a full starch degradation. Typically, a DP value for a typical pale malt would be approximately 110-160°L. In the current study, the DP values are all relatively low. The observed levels would be suitable for craft brewing where only barley is used, however there may be issues if the barley varieties in these samples were to be selected for beers where a large amount of adjuncts are used.

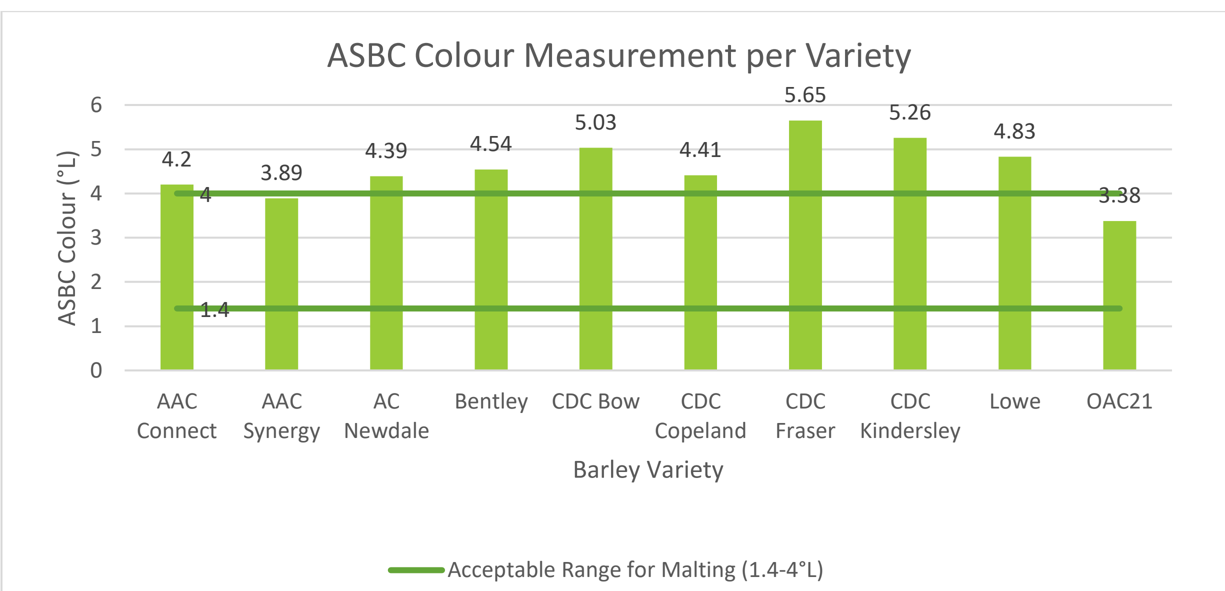
Figure 3



Colour

The colour value for pale malt should ideally be between 1.4-2.0°L. Colour is one of the most important qualitative parameters to a brewer. Generally speaking, lighter colored malts are preferred to darker malts. Most of the varieties were over 4°L, with the exception of OAC21 and AAC Synergy which had color values of 3.8 and 3.3, respectively. Overall, most of the varieties would produce wort that was too dark for most breweries, and the malt would be rejected based on colour alone.

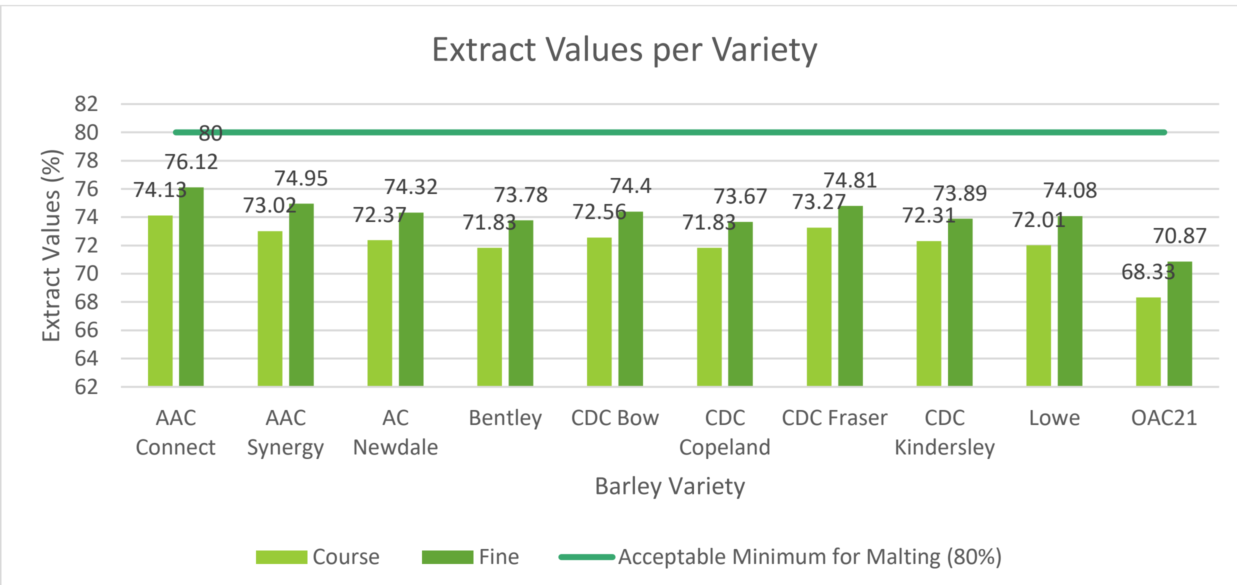
Figure 4



Extract

Malt extract is essentially the amount of sugar that can be pulled out of the barley following starch degradation. This is a very important qualitative parameter for brewers as this is essentially the sugar concentration within the bulk malt that can be used for beer. The higher the extract values, the better. This value needs to be at least 80% in order for the malt to be considered to be economically viable by the brewer. Anything less may be indicative of pre-harvest sprouting, excessive protein, or other extraneous factors that may negatively affect malt and beer quality. The extract values consist of 'course' and 'fine' values which represent the degree to which the malt has been milled. Finer ground malt tends to have higher extract values. However, brewers tend not to finely mill malt, as it can lead to issues when lautering during the brewing process. In this trial, AAC Connect and AAC Synergy were the only varieties that had acceptable extract percentages.

Figure 5

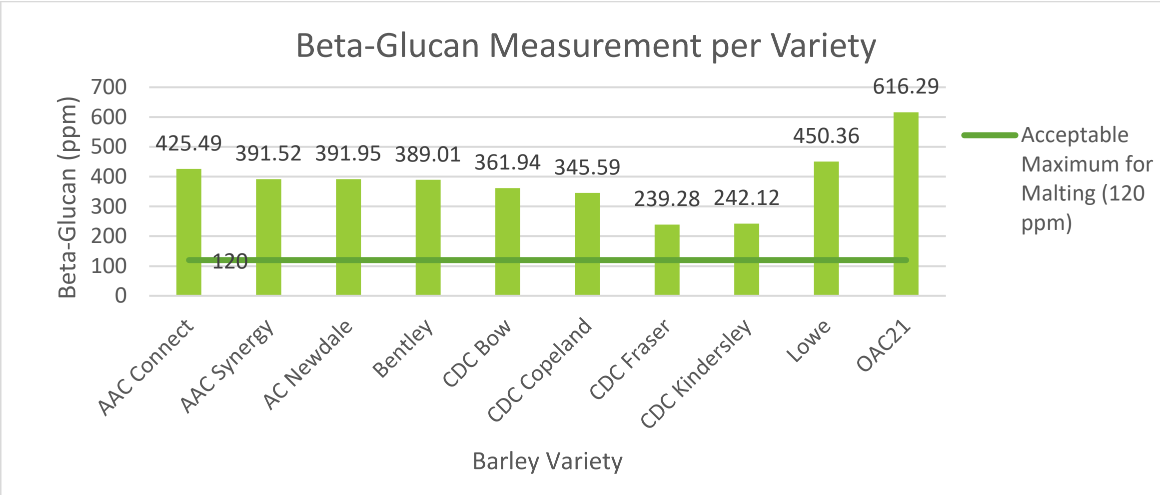


Beta-Glucan

Beta-glucan is the polysaccharide that is essentially the glue holding starch granules together within the barley kernel. Higher concentrations of beta-glucan are not desirable in the malting or brewing process. Higher levels can lengthen the amount of time required to malt the barley and can lead to longer lautering times in the brewery. Acceptable concentrations of beta-glucan are generally below 120 parts per million. All varieties in this trial have values well above the acceptable range with the closest to acceptable value observed in CDC Kindersley at 242.1 ppm and CDC Fraser with 239.2 ppm. OAC 21 had the highest with 616.2 ppm. Observed levels this high are likely due to pre-harvest sprouting.

Figure 6

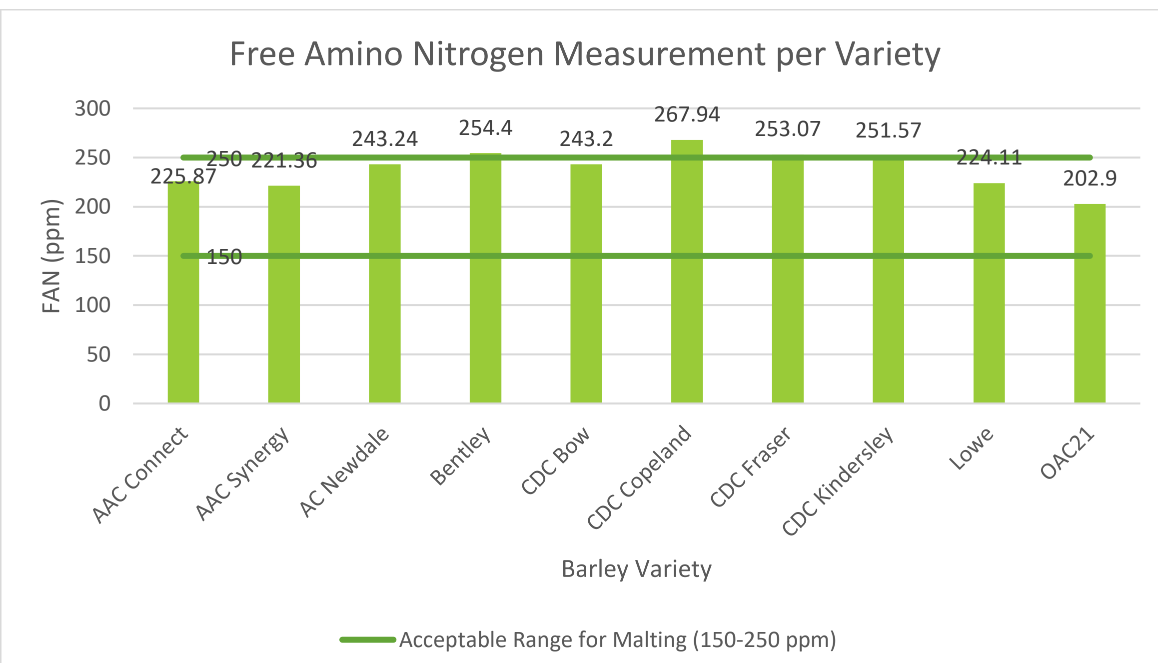
Beta-Glucan Measurement per Variety



Free Amino Nitrogen (FAN)

Free amino nitrogen values are comprised of the total amount of amino acids in the wort. This component is important for yeast health during fermentation, but excessively high levels lead to shelf stability issues in bottled beer. FAN concentration should be between 150-250 parts per million. Although on the high side, all of the varieties in this trial had acceptable levels of FAN.

Figure 7

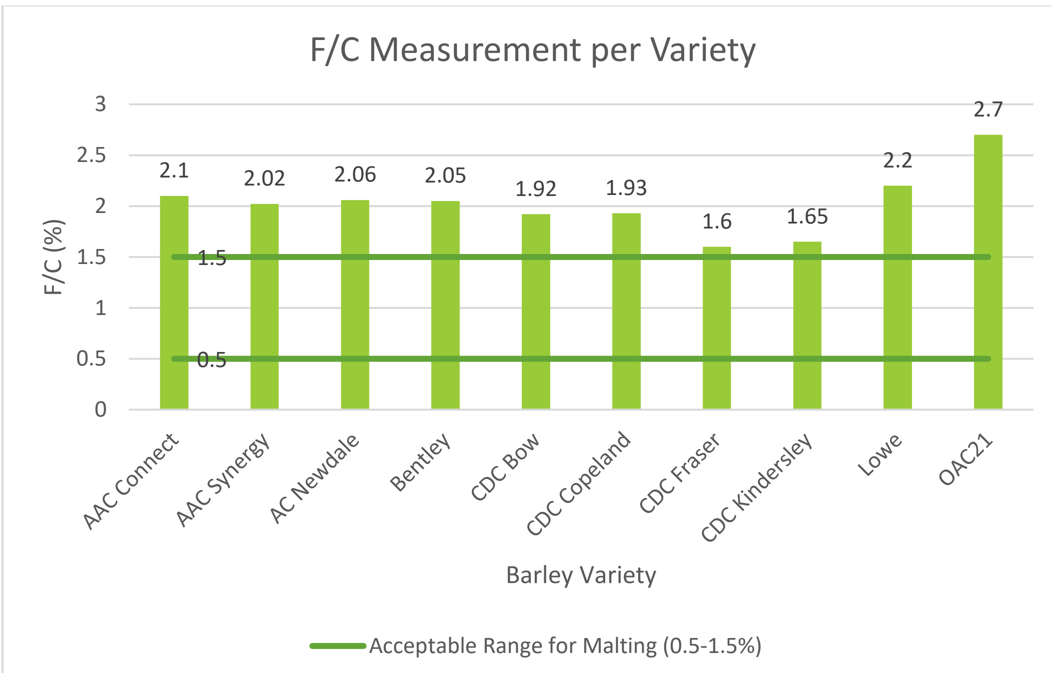


Fine/Course (F/C)

The value derived from the fine grind percentage minus the course grind percentage is called the F/C and is a measurement of the physical properties of the grist, whether it is 'glassy' or 'mealy'. Desirable levels of F/C would be between 0.5-1.5%. Higher values indicated that the malt has low homogeneity which can result in under-modification due to the 'glassy' portions of the kernels. Most varieties in the current study have values well over 1.5%. OAC 21 had a value of 2.7%, which would be completely unacceptable. Both CDC Kindersley and CDC Fraser have high values but are closer to the ideal specifications than any of the other varieties.

Figure 8

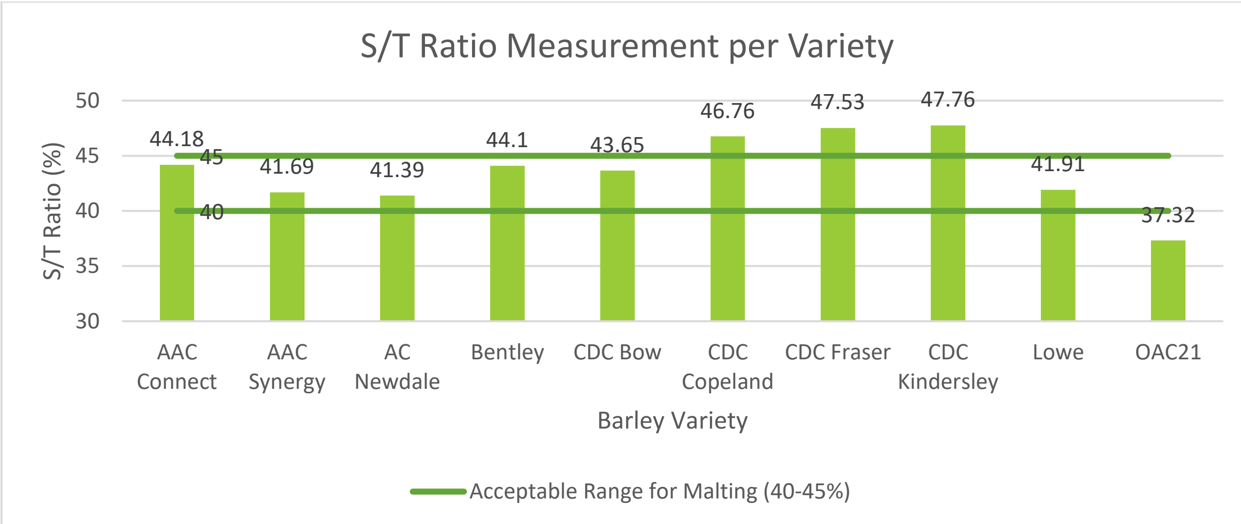
F/C Measurement per Variety



Protein & S/T Ratio

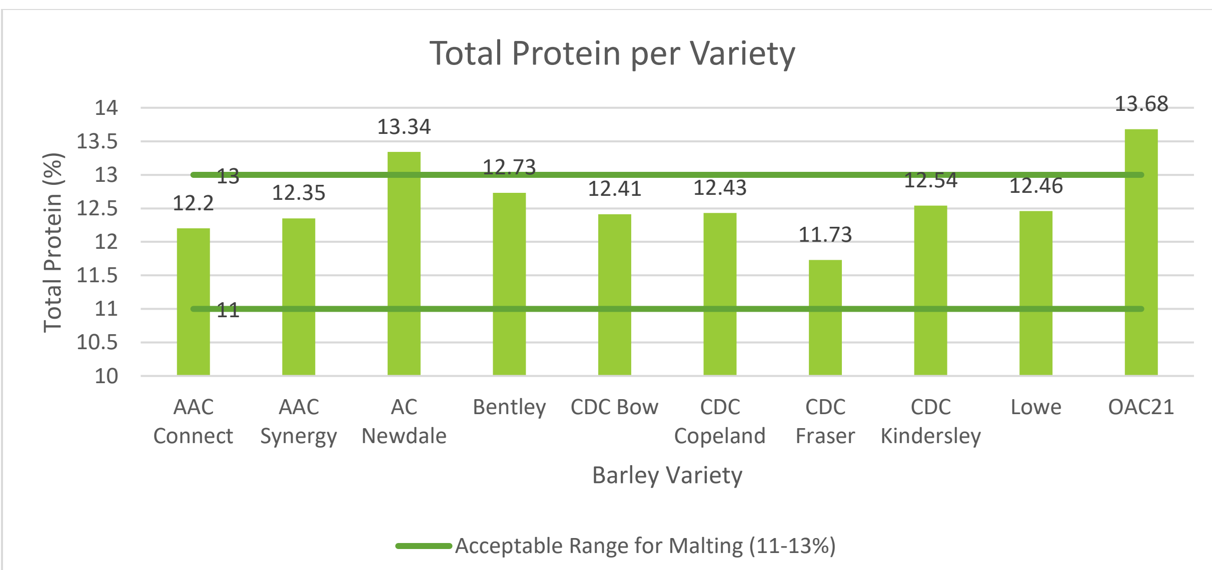
S/T is the ratio of total protein to soluble protein and is a strong measure of malt modification. Normal values for base malts tend to be between 40-45%. Although a few varieties in this trial were on the high end of that threshold, most were within the acceptable range. OAC 21 showed the lowest S/T ratio value at 37.5% of all varieties and would be considered unacceptable.

Figure 9



Total protein percentage (on a dry matter basis) should ideally be between 11-13%. Generally, lower protein results in a higher extract but lower enzymes; higher protein results in a lower extract but higher enzymes which would be useful for brewing with adjuncts like rice. Although most of the varieties are at the higher end of the acceptable range, protein levels are generally adequate. Both OAC 21 at 13.6% and AC Newdale at 13.3% are too high and may be at risk of protein hazing if used for brewing.

Figure 10



Effects of Nitrogen and Sulphur on Malt Quality

Malt quality is sensitive to nitrogen fertility. In eastern Canada the best quality is often achieved by adding little or no nitrogen. However, this can be difficult to reconcile as nitrogen also drives yield. Therefore, it is important to find a balance between yield and quality. Protein levels can indicate appropriate levels of nitrogen – if protein levels are high, nitrogen applications should be reduced. Malt data from LUARS in 2020 was left out of this analysis due to the high degree of variability caused by drought. All of the possible combinations of nitrogen rate, source, and sulphur rate were analyzed to determine their effects on malt quality.

Any Nitrogen Application

The application of any nitrogen significantly (*P=0.05*) increased the protein content of malt when compared to barley that had not been treated with any nitrogen. However, protein was the only malt characteristic that was statistically significantly affected by the comparison of any nitrogen versus no nitrogen.

Figure 11

Effects of Any Nitrogen Application on Malt Protein Content

N Applied	Protein Content (%)
Yes	11.51
No	11.96
Significance of Effect	*P=0.05*

Nitrogen Rate

Figure 12

Effects of Nitrogen Rate on Malt Quality Measurements

N Rate (kg-N/ha)	Malt Extract, Course, As-is (%)	Malt Extract, Course, Dry Basis (%)	Malt Extract, Fine, As-is (%)	Malt Extract, Fine, Dry Basis (%)	Malt Moisture (%)	S/T Ratio (%)	Total Protein (%)
35	75.07	78.65	76.69	80.32	4.53	48.088	11.48
70	75.15	78.76	76.55	78.20	4.56	48.089	11.70
105	73.48	77.12	77.18	78.92	4.72	45.000	12.70
Significance of Effect	*P=0.05*	*P=0.05*	*P=0.05*	*P=0.05*	*P=0.01*	*P=0.05*	*P=0.01*

Note. Acceptable values for malting: malt extract (all): 80% or more. S/T Ratio: 40-45%. Total protein: 11-13%

While all of the total protein measurements detailed in Figure 12 fall into the acceptable limit, the 105 kg-N/ha rate comes close to the upper threshold for malt acceptability at 13%. The lower N rates generally brought the malt closer to acceptability on the malt extract measurements, but further from acceptability on S/T ratio. Altering the rate of nitrogen application had no significant effect on the other malt quality characteristics.

Nitrogen Source

While nitrogen applications rates do affect malt quality, the different nitrogen sources did not. Urea and Environmentally Smart Nitrogen (ESN), the two nitrogen sources used in this trial, did not significantly affect malt quality in any way.

Nitrogen Rate by Nitrogen Source

The different rates of nitrogen application (35, 70, and 105 kg-N/ha) for each nitrogen source were compared. The analysis found that the rate and source did not significantly affect malt quality.

Sulphur Rate

The application of any sulphur compared to no sulphur resulted in a statistically significant difference in alpha-amylase *(P=0.05*), ASBC Colour *(P=0.10)*, Diastatic Power *(P=0.05)*, malt extract fine ground *(P=0.10)*, moisture *(P=0.05)*, pH *(P=0.05)*, and wort viscosity *(P=0.05)*.

Figure 13

Effects of Nitrogen Rate on Malt Quality Measurements

S Rate (kg/ha)	Alpha Amylase (u/ml)	ASBC Colour	Diastatic Power	Malt Extract, Course, As-is (%)	Malt Extract, Course, Dry Basis (%)	Malt Extract, Fine, As-is (%)	Malt Moisture (%)
0	39.55	7.96	85.58	74.04	77.68	75.73	4.67
12	41.70	5.58	96.12	74.99	78.57	76.49	4.53
Significance of Effect	*P=0.05*	*P=0.10*	*P=0.05*	*P=0.10*	*P=0.10*	*P=0.10*	*P=0.05*

Note. Acceptable values for malting: Alpha-amylase: 35-50 u/ml. ASBC Colour: 1.4-2.0 °L. Diastatic Power: 110-160 °L. Malt extracts (all): 80% or more.

Any Nitrogen Application within Sulphur Rate

This analysis compared the different sulphur rates (0 and 12 kg/ha) combined by whether any nitrogen had also been applied. No significant effects were found.

Nitrogen Source by Sulphur Rate

This analysis compared the two nitrogen sources (urea and ESN) and their combinations with different rates of sulphur application (0 and 12 kg/ha). No significant effects were found.

Nitrogen Rate by Sulphur Rate

This analysis compared the different nitrogen rates (35, 70, and 105 kg-N/ha) combined with the different sulphur rates (0 and 12 kg/ha). No significant effects were found.

Nitrogen Rate by Nitrogen Source by Sulphur Rate

This analysis compared each nitrogen rate, source, and sulphur rate for a total of ten combinations. The only significant effects found were FAN *(P=0.10)*, S/T ratio *(P=0.10)*, and wort protein *(P=0.05)*.

Figure 14

Effects of Nitrogen Rate, Source, and Sulphur Rate on Malt Quality Measurements

Nitrogen Source, Rate, and Sulphur Rate	FAN (mg/l)	S/T Ratio (%)	Wort Protein (%)
Urea, 35N, 0S	215.92	44.87	5.06
Urea, 35N, 12S	239.53	51.38	5.80
Urea, 70N, 0S	244.23	49.88	5.74
Urea, 70N, 12S	230.99	46.59	5.57
Urea, 105N, 0S	231.85	43.30	5.50
Urea, 105N, 12S	230.69	44.01	5.49
Urea+ESN, 35N, 0S	234.13	48.54	5.70
Urea+ESN, 35N, 12S	224.47	47.55	5.52
Urea+ESN, 70N, 0S	234.90	49.47	5.83
Urea+ESN, 70N, 12S	218.53	46.40	5.43
Urea+ESN, 105N, 0S	221.39	44.04	5.55
Urea+ESN, 105N, 0S	236.63	48.63	6.20
Significance of Effect	*P=0.10*	*P=0.10*	*P=0.05*

Note. Acceptable values for malting: Free Amino Nitrogen (FAN): 150-250 mg/l. S/T Ratio: 40-45%). Wort Protein: 9-11%.

Summary

Overall, nitrogen increased the total protein content of the barley, though the source of that nitrogen (urea versus urea and ESN), did not matter. Following this, the rate of nitrogen also had an impact on protein content, with protein levels increasing at higher levels of nitrogen treatment, and the 105 kg-N/ha pushing the 13% limit of acceptability with 12.70%. The lower nitrogen rates also brought the malt closer to acceptability on most of the malt extract measurements, but further from acceptability on S/T ratio.

When isolated, the application of sulphur positively impacted all of the measurements that it statistically affected, bringing colour, diastatic power, and three of the extract measurements closer to the acceptable ranges.

The fact that the combination of nitrogen and sulphur in the analyses were generally unremarkable suggests that the benefits of the nitrogen and sulphur applications are largely independent of each other, as far as malt quality is concerned. The data suggest that applications of none or 35 kg-N/ha and 12 kg-S/ha are most conducive to malt quality in northern Ontario.

Algoma On-Farm Trial Results

Three dual purpose varieties of malting barley were tested on-farm on two locations in Algoma district. These varieties, AC Newdale, AAC Synergy, and AC Metcalfe, can be used for either malting or feed if they do not meet the quality requirements for malting. These varieties were assessed for yield and samples were tested for barley quality and malt quality. Bentley was also grown in the on-farm trials, but those fields were heavily eaten by geese and that data was removed from the analysis.

Yield

When averaged across locations and years, AC Metcalfe averaged 0.56 tonnes per hectare, AC Newdale averaged 1.12 tonnes per hectare, and AAC Synergy had the highest yield with 1.52 tonnes per hectare.

Malt Quality

Figure 14

AC Newdale Malt Quality Results

Measurement	Acceptable Range	Sample Result
Protein	11-13%	13.8%
Alpha Amylase	35-50 U/ml	28.6 U/ml
Diastatic Power	100-160 °L	74.3 °L
Colour	1.4-2.0 °L	10.2 °L
Extract, Course	>80%	70%
Extract, Fine	>80%	71.3%
Beta-Glucan	<120 ppm	111.18 ppm
FAN	150-250 ppm	245.43 ppm
S/T Ratio	40-45%	46.68%
F/C	0.5-1.5%	1.4%

Figure 15

AC Metcalfe Malt Quality Results

Measurement	Acceptable Range	Sample Result
Protein	11-13%	15%
Alpha Amylase	35-50 U/ml	23 U/ml
Diastatic Power	100-160 °L	68.8 °L

Colour	1.4-2.0 °L	12.4 °L
Extract, Course	>80%	68.3%
Extract, Fine	>80%	70%
Beta-Glucan	<120 ppm	259.28 ppm
FAN	150-250 ppm	248.8 ppm
S/T Ratio	40-45%	43.45%
F/C	0.5-1.5%	1.8%

Figure 16

AAC Synergy Malt Results

Measurement	**Acceptable Range**	**Sample Result**
Protein	11-13%	13.2%
Alpha Amylase	35-50 U/ml	27.9 U/ml
Diastatic Power	100-160 °L	71.4 °L
Colour	1.4-2.0 °L	10.1 °L
Extract, Course	>80%	71%
Extract, Fine	>80%	72.3%
Beta-Glucan	<120 ppm	130.77 ppm
FAN	150-250 ppm	255.02 ppm
S/T Ratio	40-45%	48.35%
F/C	0.5-1.5%	1.4%

The malt results for the on-farm trials ranged considerably. The protein levels were high but were not too far off the 13% threshold for malt acceptability. Similarly, alpha amylase was slightly too low with AC Metcalfe falling the furthest below the 35 u/ml lower threshold at 23 u/ml. The diastatic power thresholds are also low, making them potentially acceptable for craft brewing, but not for commercial brewing with adjuncts like rice or corn. The ASBC colours are all very high and would cause the barley to be refused for malting. The course and fine extracts also fall below the target of at least 80%, with AAC Synergy coming closest at 71% and 72.3% for course and fine grinds respectively. AC Newdale had acceptable beta-glucan measurements with 111.18 ppm, while AAC Synergy was slightly too high, and AC Metcalfe was very high. The FAN measurements were at the high end, but AC Newdale and AC Metcalfe were within the acceptable range, while AAC Synergy was just over. AC Metcalfe was within the range for S/T ratio, while AAC Synergy and AC Newdale were slightly too high. AC Newdale and AAC Synergy had acceptable measurements for F/C, while AC Metcalfe was slightly over the upper threshold. In summary, AC Newdale was deemed acceptable on three of the 10 measurements and was close to acceptability on two others. AC Metcalfe was deemed acceptable on two of the 10 measurements and was close to acceptability on two others as well. AAC Synergy was deemed acceptable on only one of the 10 measurements but was close to acceptability on four others.

Results Summary

Drawing from the overall yield data, AAC Synergy had one of the highest yields at all three sites. Furthermore, yield stability regression analysis revealed that AAC Synergy yields were relatively stable across sites and years. This suggests that this variety is likely to be a superior yielding variety under conditions that limit yields as well as conditions that enable production of higher yields. AAC Synergy was one of the two dual-purpose varieties, the other being AC Newdale. AC Newdale also had reasonable yields, but was consistently lower than AAC Synergy.

Beyond the dual-purpose varieties, AAC Connect, CDC Bow, and CDC Kindersley were consistently statistically associated with relatively high yields at all sites. From a yield perspective, each of these varieties appear to be adequately suited at each site. Based on the variety findings, CDC Kindersley, CDC Fraser, and AAC Synergy were the best candidates for malting.

AAC Synergy was also the leading candidate to emerge from the on-farm trials. It had the highest average yield, and while none of the varieties in the on-farm trial had outstanding malt quality, AAC Synergy had the highest number of characteristics that were either within the acceptable range for malting or close to it.

The malting barley variety trials results showed that there is potential to grow many of these varieties in northern Ontario, however, it may be necessary to adjust cultural practices in order to achieve acceptable malt quality standards. Reducing rates of nitrogen fertilizer application, adjustment of seeding rates, the aggressive use of fungicides for disease management, and harvesting grain before full maturity may overcome some of the environmental challenges posed by growing barley varieties developed in western Canada in eastern Canada. Growing barley for malting requires management intensity levels comparable to that of wheat grown for milling.

Based on the variety malting trial, CDC Kindersley, CDC Fraser, and AAC Synergy are the best candidates for use in northern Ontario. The malt results seen in this trial are similar to other trials conducted elsewhere in eastern North America, where weather can present a challenge in achieving malt quality. These regions have been experimenting with malt barley varieties developed in Europe, which has a climate that is more similar to that of eastern North America. In northern Ontario, these European varieties may be more successful in terms of malting quality than varieties developed in western Canada.

The nitrogen and sulphur trial showed that only minimal nitrogen is necessary when cultivating barley for malting. Little or no nitrogen generally improved malt characteristics, while applications of sulphur also generally improved malt characteristics. Between urea and the ESN/urea combination, there was no significant differences in malt quality.

The overall recommendation arising from this project for producers looking to cultivate malting barley in northern Ontario would be to grow AAC Synergy with little nitrogen and 12 kg-S/ha. This variety and rate of sulphur and nitrogen applications resulted in the most promising results seen in this trial. The characteristics of the malt quality results meant that the data had to be analyzed collectively, resulting in one blanket recommendation, rather than region specific recommendations for variety and nitrogen and sulphur rates.

Increasing nitrogen rates drives yields, but at a certain point it also has the potential to reduce malt quality. Farmers interested in growing barley with the intention of malting should see malt quality as their primary goal, while nitrogen-driven yield should be a secondary concern. Other methods such as not growing malting barley following legumes, choosing high yielding varieties, and careful management practices can result in increased yields with minimal nitrogen use.

Acknowledgments

This project was funded in part through the Canadian Agricultural Partnership (the Partnership), a federal-provincial-territorial initiative. The Agricultural Adaptation Council assists in the delivery of the Partnership in Ontario. This project was also funded by Grain Farmers of Ontario.

The Northern Ontario Farm Innovation Alliance would like to thank Dr. Kenneth Janovicek, Dr. Aaron Mills, Dr. Bill Deen, the Canadian Malting Company, and the staff of the Ontario Crops Research Stations Emo and New Liskeard, the Lakehead University Agricultural Research Station and the Rural Agri-Innovation Network for their assistance in the completion of this project.