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Fertigation of Wheat and Canola In Southern Alberta

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ABSTRACT

An irrigation study in southern Alberta compared spring banded nitrogen (N) to spring banded N plus fertigation at three plant growth stages for spring wheat (*Triticum aestivum* L.) and canola (*Brassica napus* L.). Yield and quality impacts were quantified when N fertigation was applied to: [1] wheat at early tillering, flag leaf, and anthesis stages, and [2] canola at the four leaf rosette, bolting, and early flowering stages. For both crops, fertigation could replace some spring banded N without a yield effect. However the results revealed that for canola grown with a large amount of N, applying it all in the spring often generated higher yields than if an equivalent level of N was delivered at later stages by fertigation. Canola oil concentration declined marginally (about 1%) from no applied N to the high rate of applied N. Application of more than 60 kg N ha⁻¹ and delayed application each increased wheat protein content. Comparing revenues to costs, fertigation did not improve profit margins for canola growers. When growers applied 90 or 120 kg N ha⁻¹ in the spring, fertigation was financially counterproductive. In contrast, the main benefit to wheat growers from fertigation was higher grain protein, especially with N applied at latter growth stages. When protein premiums increase during the growing season, fertigation would facilitate growers to obtain higher net returns than they would otherwise.

Keywords: net return, fertigation, nitrogen, canola, wheat

INTRODUCTION

The majority of irrigated land in Canada is located in southern Alberta. Over the past 30 years farmers in this area have adopted centre pivot irrigation systems, allowing for light and frequent supply of water to land. Low pressure centre pivot systems now account for 75% of irrigation

systems (AAF 2018) with the remainder consisting of high pressure centre pivots, wheel moves and gravity feeds. About one-third of the irrigated area is cropped to annual cereals, one-third to forage, 11% to oilseeds, and 22% to specialty crops. In 2016, the main irrigated crops were wheat (*Triticum aestivum* L.) (22%), barley (*Hordeum vulgare* L.) (11%), alfalfa (*Medicago sativa* L.) and mixtures (12%), canola (*Brassica napus* L.) (10%), and pulses and specialty crops (18%) (AAF 2018).

Nitrogen (N) is the most limiting nutrient for irrigated crop production in Alberta (McKenzie et al. 2013). Common practice is to apply all of the crop nutrients in the spring, either before or at seeding. With warm moist soil, ammonium is quickly converted to nitrate form but nitrate-N is subject to leaching or denitrification as plant requirements and uptake are low early in the growing season (Cameron et al. 2013). Modifying N application by reducing the spring banded N rate and then applying N during the growing season could better match available N with crop requirements, similar to controlled release urea. Beres et al. (2018) reported that for winter wheat splitting N application between fall and spring, and utilizing a controlled release urea had higher yield and grain protein. For spring seeded crops of wheat, barley, canola, and corn (*Zea mays* L.), Grant et al. (2012) reported split application of N or use of a controlled release urea (CRU) did not consistently improve crop yield or grain N concentration. Controlled release urea was found to increase N-use efficiency and lower losses, including N₂O (Shoji et al. 2001). The delivery of N to crops also can be scheduled through time using fertigation, the application of liquid N (urea ammonium nitrate, or UAN) through on-farm irrigation infrastructure. Potential advantages include uniform N distribution, flexibility in timing fertilizer application, reduced labour requirements, and lower fertilization rates (Schwankl 2012). But

there is a trade-off: UAN is generally more expensive than urea, the cost difference varying over time and location (Farm Futures 2018).

For growers of canola and hard red spring wheat (HRSW) under irrigation in southern Alberta, the potential financial net benefits from fertigation are not well understood. Splitting N applications between the time of seeding, and tillering or stem elongation has been reported to increase irrigated wheat grain yield and plant N uptake (Ebrahimian et al. 2014). Splitting the application of N has not always demonstrated a yield benefit, but can increase grain N concentration or total plant N (Grant et al. 2012; Velasco et al. 2012). Moreover, fertigation involves additional fixed expenses, such as injection pumps, and differences in variable costs, most notably the difference in price between liquid and other forms of N. The managerial burden also is larger as the timing of fertigation is critical. Thus, in addition to the possible agronomic advantages of fertigation for annual cropping, there is a practical need to know if it is economic, and if so, under what conditions. The total cost of applying N by fertigation could be higher than applying a similar total rate of N in the spring, depending on the expense of an injection pump, labour and the cost of the UAN.

To realize its purpose this study has two objectives: [1] to quantify the yield and seed effects of N fertigation applied to wheat and to canola, and [2] to determine the financial implications for growers. Fertigation was at three stages, early tillering, flag leaf, and anthesis for wheat, and the four leaf rosette stage, bolting, and early flowering for canola. Information generated by analyzing variations in net return by the timing of N application will help growers decide if fertigation is financially advantageous, and if so, the crop and timing for profit maximization.

MATERIAL AND METHODS

Field data

An irrigation field study of N applied at seeding and in-crop by fertigation on wheat and canola was conducted from 2013 through 2016 at Lethbridge, Alberta (49°41'N, 112°44'W, 900m). The undertaking transpired on land controlled by Alberta Agriculture and Forestry (AAF) that had been irrigated and continuously cropped for many years. While the location of the experiment was moved within the field annually, the site is a homogenous Dark Brown Chernozemic soil, Lethbridge series, with Sandy Clay Loam texture. Soil organic matter content of the 0-15 cm depth varied from 3.0% to 3.5%, and pH of this same depth ranged from pH 7.5 to pH 8.0. Table 1 reveals spring soil nitrate concentrations varied slightly in most years but were greatest in 2015, especially in the 30-60 cm and 60-90 cm depth increments. The April through September precipitation at this site is typically about 290 mm, ranging from 181 mm to 419 mm and irrigation ranged from 83 mm to 196 mm (Table 2).

The test crops were hard red spring wheat and hybrid canola. Test design consisted of a check of 0 kg N ha⁻¹, four rates (30, 60, 90 and 120 kg ha⁻¹) of N side-banded urea (46-0-0) at the time of seeding, and one rate (60 kg ha⁻¹) of side-banded ESNTM (controlled release N; Environmentally Smart Nitrogen) (44-0-0). Each level of N and the check received five fertigation treatments of UAN (28-0-0) with 12 mm of water. The fertigation treatments were: [1] a check without UAN but water was applied, [2] application of 30 kg N ha⁻¹ at early tillering for wheat, the fourth leaf rosette stage for canola, [3] application of 30 kg N ha⁻¹ at flag leaf for wheat, bolting stage for canola, [4] application of 30 kg N ha⁻¹ at anthesis for wheat, early flowering for canola, and [5] application of 30 kg N ha⁻¹ at all three growth stages for both crops. Water samples were collected during the irrigation to confirm the N application rate.

Wheat and canola were direct seeded using a plot drill with disc openers on 25 cm row spacing. Plots were eight rows wide (2 m) by 10 m long at seeding but trimmed to 7 m prior to harvest. Table 3 identifies the specific wheat and canola cultivars sown in each of the four growing seasons. Each year hard red spring wheat was seeded at 380 seeds m⁻² and herbicide-tolerant hybrid canola was seeded at 140 seeds m⁻². Phosphate fertilizer (0-45-0) was seed-placed at a rate of 25 kg P₂O₅ ha⁻¹ with both wheat and canola. Soil moisture was monitored frequently by a neutron probe and these data were the basis for irrigation management. Soil moisture was maintained between 60 and 100% of field capacity to ensure optimum yield. When necessary, irrigation (non-treatment related) with the linear system applied 15 to 25 mm per irrigation. A plot combine harvested each crop to determine yield. Whole grain samples were used to quantify protein and oil concentrations using near-infrared reflectance spectroscopy technology (Foss Decater GrainSpec).

The N fertilizer treatments were arranged using a randomized split block design. To facilitate irrigation activities, fertigation treatments were main plots, and urea N banded at seeding were sub-plots. Due to fertigation logistics, there were two sets of treatment observations for each of two blocks, for a total of 120 plots per crop. The irrigation system was a standard linear system. The throw diameter of each sprinkler was about 6 m, and sprinklers were spaced about 2 m apart along the linear irrigation system. This required separation (about 15 m) between main-plots to prevent off-target water and fertilizer application. Considerable non-plot area within the experiment was necessary. Crops were fertigated using an injection pump that injected liquid N into the pressurized irrigation water just before the linear irrigation system. In this study, the tank for liquid N and the injection pump cost \$2800. A commercial grower might

require a larger liquid N tank, adding no more than about \$500 to the cost, or less than \$10 ha⁻¹ fixed cost.

Economic model

The net return (NR) for each replicate in the experiment was computed as the difference between total revenue and total cost. Total revenue was the product of price (\$ Mg⁻¹) and yield (Mg). For wheat, protein content has a significant impact on price, which varies through time. The base crop prices used in the model were 10-yr averages, \$205.83 Mg⁻¹ for wheat (13.5% protein) and \$426.77 Mg⁻¹ for canola (AAF, 2015a). Protein premiums for wheat were estimated from reported premiums for 1998/99 to 2014/15 (AAF, 2015a). The data reported five levels of protein (11.5, 13, 13.5, 14, 14.5), the remaining 0.5% protein increments from 11.0 through 15.5 were based on the price increments reported by the Canadian Wheat Board for 2004/05 to 2008/09 (G3 Canada Ltd. 2017). The base protein premium schedule was an average over all 17 years. The high premium values were determined using the 4-yr average of the four highest premiums, and the low premiums were the 4-yr average of the four lowest premiums over the 17 years (Table 4). Years with high protein premiums also had high discounts when protein was low (Table 4).

Production costs included seed, fertilizer, pesticides, irrigation, fertigation when used, machinery, grain hauling, land rental, and insurance. The costs that differed by the treatments in this study were N fertilizer, fertigation, and harvest machine and hauling costs that are positively correlated with crop yields. The 4-yr average cost of urea N was \$1.36 kg⁻¹ and P₂O₅ was \$1.21 kg⁻¹ (AAF, 2015c). The price for ESN™ (\$1.48 kg⁻¹) and UAN (\$1.45 kg⁻¹) were based on the urea price and price differentials found for these two N products. Superphosphate (0-45-0) was

applied with the seed at 25 kg P_2O_5 ha⁻¹. Table 5 reveals the costs for seeding, field spraying, combining and grain hauling were the same for canola and wheat but because of physical dissimilarities between the two crops, swathing and irrigating costs were different. Machinery, seed, herbicide, and other farm operating costs were based on 2014 costs using custom rates for the field operations (AAF 2015b; 2015d). Irrigation costs were \$4.61 ha⁻¹ higher with fertigation to account for the capital cost of the fertigation equipment.

Statistical analysis

There was only one spring banded rate of N applied as ESNTM, 60 kg N ha⁻¹. A comparison of ESNTM and urea at 60 kg N ha⁻¹ used analysis of variance to determine whether the fertilizer form at seeding at this one rate was correlated with crop yield and NR. There was no statistically significant difference in yield or NR by N form, hence the remaining analyses of N rate and fertigation was for the banded urea. Analysis of variance was used to evaluate the significance of banded N rate, fertigation treatment, and the interaction of these two main effects. The blocks and years were treated as random. The same model was used for crop yield, protein, oil, and NR. Statistical differences in the means of these variables were based on $p=0.05$.

To determine the extent to which banded N or banded plus fertigation applied N influenced yield and net return, comparisons were made based on total N ha⁻¹ applied. For example, a total of 30 kg N ha⁻¹ could be obtained from banding only and no fertigation, or zero banded N plus one of the three fertigation treatments that applied 30 kg N ha⁻¹. Similar comparisons were made for total N of 60, 90, and 120 kg N ha⁻¹, though the 90 and 120 kg N ha⁻¹ rates also included the fertigation treatment of fertigation at all three plant growth stages. The total N applied by banding and banding plus fertigation was not balanced, with 150, 180 and 210

kg N ha⁻¹ attained only with fertigation plus spring banded N. Contrasts for total N of 150, 180, and 210 kg N ha⁻¹ were compared against the banded rate of 120 kg N ha⁻¹ without fertigation to determine whether there was a significant response from fertigation when applying more than 120 kg N ha⁻¹.

RESULTS AND DISCUSSION

Table 6 describes the results of the statistical test of fertilizer form, urea and ESNTM, at the 60 kg N ha⁻¹. There was no difference in crop yield or NR by fertilizer type. Neither the interaction with fertigation nor the main effect of fertilizer type were significant for either crop ($p>0.05$). At a banded N fertilizer rate of 60 kg N ha⁻¹, average canola yield was 3581 kg ha⁻¹ and wheat was 5202 kg ha⁻¹ (data not shown). At 60 kg N ha⁻¹, the average NR was \$672 ha⁻¹ for canola and \$337 ha⁻¹ for wheat (data not shown). There was also no difference in grain protein for canola ($p=0.96$). The ESNTM fertilizer had higher protein concentration for wheat, but this effect was not statistically significant (13.47 vs. 13.13, $p=0.102$). The analysis which follows focused on the urea fertilizer form as there was no statistically significant difference in yield and NR by N form.

The yield and quality results for the two fertilizer forms were consistent with the findings of Grant et al. (2012) for barley, wheat, and canola, and of Blackshaw et al. (2011) for canola. Blackshaw et al. (2011) found canola yield to be higher with ESN for about 20% of the site-years with no difference for 70% of the site-years. There was no difference in seed quality by N source reported for the two studies, but Grant et al. (2012) found grain N concentrations tended to be lower with urea, but not consistently lower.

Crop yield

The analysis for yield with main effects of banded N at seeding and fertigation timing indicated for canola the interaction was statistically significant enough to be of interest ($p=0.052$, Table 7). The addition of N by fertigation increased canola yield when spring banded N was low, but with spring banded rates of 90 kg N ha⁻¹ and higher, there was no yield benefit from fertigation (Table 8). Fertigation at the flowering stage of canola did not significantly increase yield over that of no fertigation, regardless of the rate of spring banded N. With low rates of spring banded N, fertigation at the 4th leaf or bolting supplied some of the N required for plant growth and crop yield. Contrasts compared canola yield at the same total N (banded plus fertigation) (Table 9). When total N was 30 or 60 kg N ha⁻¹, yield was the same whether the N was banded, applied by fertigation, or was a combination of banded and fertigation. With total N of 90 and 120 kg N ha⁻¹, there was a tendency for higher yield when all of the N source was spring banded (184, $p=0.065$, and 170 kg ha⁻¹, $p=0.088$, respectively). One fertigation timing combined with banded 60 or 90 kg N ha⁻¹ had higher average yield than three fertigation timings combined with banded 0 or 30 kg N ha⁻¹ (157 kg ha⁻¹, $p=0.129$; 204 kg ha⁻¹, $p=0.049$, respectively, data not reported). Banding the three time periods negatively influenced canola yield, possibly because of the lower yield observed when fertigation was applied at flowering. Total applied N of 150, 180, and 210 kg N ha⁻¹, had a same yield as 120 kg N ha⁻¹ of banded N ($p=0.47$ to 0.98).

The canola yield results by N timing, spring banding and fertigation in this study (Table 8), were consistent with the results of urea and CRU reported by Grant et al. (2012) with half of the N applied at seeding and half in-crop. The split application had similar yield to applying all of the N in the spring. The CRU was designed to provide N throughout the growing season,

similar to split N application and fertigation. In this study, the yield benefits of fertigation declined with higher banded N rates in the spring, and with fertigation at all three time periods. Fertigation at flowering was not yield enhancing. The canola results from this study were consistent with split application of N for winter wheat, though N banding was in the fall for winter wheat (Beres et al. 2018).

Fertigation of N on canola after seeding needs to be used with caution. One application of N (30 kg N ha^{-1}) by fertigation at either the 4th leaf or bolting stages could be used to substitute for spring banded N without influencing canola yield, but only if the spring banded rate is not more than 60 kg N ha^{-1} . With spring banded rates of 90 kg N ha^{-1} , or more, canola yield will be lower if fertigation is used to replace spring banded N. For canola, N applied after bolting had no yield benefit.

Yield of spring wheat was influenced by the interaction of the spring banded N rate and fertigation ($p=0.018$, Table 7). Similar to canola, fertigation contributed to yield only with low rates of spring banded N (Table 10). At 0 and 30 kg N ha^{-1} of spring banded N, one fertigation increased yield, and the yield for three fertigation timings was greater than one fertigation. At 60 kg N ha^{-1} of spring banded N, three fertigation timings had higher yield than no fertigation (453 kg ha^{-1}) and fertigation at anthesis (309 kg ha^{-1}), but the yield was the same as one fertigation at either tillering or the flag leaf stage. At 90 kg N ha^{-1} banded N, one or three fertigation timings had higher average yield than no fertigation (258 kg ha^{-1}). Contrasts of wheat yield for the same total N (banded plus fertigation) found no difference in yield based on the N source (Table 9). Whether the N source was from banded urea or N applied by fertigation, wheat yield was the same for a given amount of total applied N. Total applied N, banded plus fertigation of 150, 180

and 210 kg N ha⁻¹ had the same yield as spring banding 120 kg N ha⁻¹ without fertigation ($p=0.21$ to 0.56).

The yield effect of fertigation in this study on spring wheat had results consistent with post-emergence N application on spring wheat (Beres et al. 2008), split N on winter wheat (Beres et al. 2018), and split N and CRU on spring wheat (Grant et al. 2012). The timing of the N application, or release, had less influence on wheat yield than the total rate of N applied. In a two-year study conducted under humid rainfed conditions, the recovery of fertilizer 15N by spring wheat was increased by 61% when applied at the boot stage rather than at seeding (Tran and Tremblay 2000). However, improvements in fertilizer N efficacy due to split application are generally greater in environments with a high risk of N loss early in the growing season.

As with canola, yield benefits of fertigation declined with higher rates of banded N, and fertigation at the anthesis stage of wheat (flowering for canola) had less yield benefit than either at tillering or flag leaf. This study showed that N fertigation on hard red spring wheat could substitute for spring banded N with comparable yield produced from equivalent total N application rates.

Grain quality

The protein concentration of canola and wheat were significantly influenced by spring banded N ($p<.0001$) and fertigation ($p<.0001$). The interaction was not significant for either crop. Protein was higher with increased banded N and with fertigation (Table 11). Canola protein was 8.7 g kg⁻¹ (4%) higher at the high banded N rate compared to no banded N, and was higher with fertigation at all three timings, 13.3 g kg⁻¹ (6%). The protein concentration for wheat increased with N, 12.6 g kg⁻¹ (10%) and 20.2 g kg⁻¹ (16%), respectively, for banded and

fertigation. Canola oil concentration was influenced by spring banded N ($p=0.050$) and by fertigation ($p<.0001$), with the interaction not significant. Oil concentration declined marginally (about 1%) from no applied N to the high rate of applied N, either banded or by fertigation (Table 11). When excluding the 120 kg N ha⁻¹ banded rate and three fertigation applications, oil concentration was essentially the same across N rates and one fertigation. Rates of N application to canola up to 90 kg ha⁻¹, whether spring banded or by fertigation, did not adversely impact oil concentration. Fertigation at all but the flowering stage reduced oil concentrations from 0.7 to 1.3 percentage points.

Higher rates of fertilizer N have shown increased grain N concentrations (McKenzie et al. 2006; Beres et al. 2008; Grant et al. 2012). For this study, the protein response to N for canola was less than for spring wheat. The lower protein response for canola was beneficial because oil concentration in the seed was reduced less than if there had been a larger increase in protein. Fertigation of wheat at later growth stages increased grain protein, consistent with McKenzie et al. (2006) and Beres et al. (2008). The increase in grain protein concentration in this study was higher than reported by McKenzie et al. (2006), though the two studies had similar N application rates in-crop.

Net return

The interaction of the spring banded N fertilizer and fertigation had a marginally significant influence on NR for canola ($p=0.052$, Table 7). For canola, when spring banded N was ≤ 30 kg N ha⁻¹, fertigation marginally increased the NR from the yield benefit of increased total N. However, fertigation of canola at flowering provided no economic benefit over no fertigation (Table 12). There was a tendency for the NR to be lower when fertigation was at

flowering, compared to either the 4th leaf or bolting stage (\$35 ha⁻¹, $p=0.103$). When 30 kg N ha⁻¹ was banded, the NR from all fertigation options was the same (\$598 to \$662 ha⁻¹), but only fertigation at bolting had significantly higher NR than no fertigation. Multiple fertigation timings with low banded N provided no economic benefit compared to one fertigation at either the 4th leaf or bolting. When banding 60 kg N ha⁻¹, or more, fertigation had no NR benefit, and at 90 and 120 kg N ha⁻¹, fertigation at all three times was less profitable. Fertigation at earlier growth stages was generally profitable when banded rates of N were ≤ 30 kg N ha⁻¹. When comparing NR based on total N applied by banded only versus banded plus fertigation, the NR with banded only N was always greater than combinations of banded N and fertigation, but significant for only the high banded rates of 90 (\$86 \$ ha⁻¹) and 120 N kg ha⁻¹ (\$80 ha⁻¹) (Table 9). When the total applied N was 30 or 60 kg ha⁻¹, the N source had no significant effect on NR and fertigation could be used to substitute for spring banded N. Total N of 150, 180 or 210 kg N ha⁻¹ had lower NR of \$48, \$152, \$149 ha⁻¹, respectively, than 120 kg N ha⁻¹ banded ($p=0.45, 0.062, 0.066$).

The general N recommendation for irrigated canola is approximately 100 kg N ha⁻¹ (McKenzie et al. 2013). This study confirmed the NR from irrigated canola was highest with at least 90 kg N ha⁻¹, banded plus fertigation N. The NR at 90 kg N ha⁻¹ banded without fertigation was as high as other combinations of banded plus fertigation. The 60 kg N ha⁻¹ banded plus fertigation at bolting was the only system with less than 90 kg N ha⁻¹ banded N that had similar NR to the banded 90 kg N ha⁻¹ without fertigation. The NR was lower for all other systems with banded 60 kg N ha⁻¹, or less banded N. Splitting the application of N on canola by using fertigation did not increase yield enough to cover the additional costs, primarily the N cost. At recommended N rates, there was no yield advantage from fertigation, similar to what has been observed with split application of N (Grant et al. 2012), that resulted in no profit advantage.

For hard red spring wheat, the N applied by spring banded and by fertigation affected the NR, but the interaction of the two factors was not significant ($p=0.362$, Table 7). The N applied contributed to yield and to wheat price through grain protein (Tables 13 and 14). With average premiums for protein, the base premiums (Table 4), the price of wheat increased up to 6.5% with additional spring banded N (Table 13). Wheat price was highest with fertigation at all three time periods and lowest without fertigation (Table 14). At the base protein premiums, NR was highest with up to 60 kg N ha⁻¹ (Table 13), and with fertigation at the flag leaf or the anthesis stage of growth (Table 14). The late fertigation contributed less to wheat yield (Table 10) than to wheat protein and price. At the base premium, there was no benefit from three fertigations. Fertigation at tillering had lower NR (\$75 ha⁻¹, $p=0.068$) than at flag or anthesis, primarily because protein was lower (0.75%, $p<.0001$) when fertigation was at the earlier growth stage. With high protein premiums (Table 4), the highest NR was with 120 kg N ha⁻¹ banded in the spring (Table 13), and with three fertigations (Table 14). The benefit of the higher application of N was almost entirely due to higher wheat protein and price (Tables 13 and 14). In contrast, when the protein premium was low, or there was no premium for wheat protein, an application of 30 kg N ha⁻¹ had the highest NR and there was no NR benefit to fertigation (Tables 13 and 14). With the low protein premium, the wheat price varied by less than \$6 t⁻¹ (3%) across the banded N rates and fertigation treatments. Without protein premiums, the yield benefit from additional N wheat was generally negated by the higher cost of N. Contrasts to compare equal N amounts, whether from banded or fertigation, indicated there was no significant difference to NR across the different combinations of banded and fertigation N. The NR at total N of 150, 180 and 210 kg N ha⁻¹ was not different from 120 kg N ha⁻¹ applied as banded N (-\$27 to \$6, $p=0.77$ to 0.93), at the base protein premiums.

The benefit of fertigation on spring wheat was primarily dependent on the premium paid for high protein wheat. McKenzie et al. (2006) reported the additional revenue from in-crop N application was less than the cost. At the time of this study protein premiums were less than the 1998-2015 average. Smith et al. (2003) determined optimum N rates to be up to 60% higher with high protein premiums, when compared to no premium. If premiums were known at seeding, higher N rates could be applied to wheat; however, the premium levels are not known until wheat harvest and protein levels of major wheat growing regions are known. Since spring banded N can be substituted with fertigation N, later season in-crop application of N by fertigation could be used to boost grain protein and the price to the producer, if markets indicate there will be average to higher premiums for protein.

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REFERENCES

- Alberta Agriculture and Forestry (AAF). 2015a. Agriculture Statistics Yearbook 2014. Statistics and Data Development Branch. Edmonton: Alberta Agriculture and Forestry. Online [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/sdd15546](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd15546) (2 Oct 2018).
- Alberta Agriculture and Forestry (AAF). 2015b. AgriProfit\$: 2015 Cost and Return Benchmarks for Crops and Forages Dark Brown Soil Zone. Online [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/econ10237/\\$FILE/15dk%20brown.pdf](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ10237/$FILE/15dk%20brown.pdf) (accessed 2 Oct 2018).
- Alberta Agriculture and Forestry (AAF). 2015c. Average Monthly Prices for April 2014. Online [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/sdd14843](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd14843) (accessed 2 Oct 2018)
- Alberta Agriculture and Forestry (AAF). 2015d. Custom Rates Survey summary 2014. Online [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/inf15309](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/inf15309) (accessed 2 Oct 2018).
- Alberta Agriculture and Forestry (AAF). 2018. Alberta Irrigation Information 2017. Report by the Basin Water Management Section, Irrigation and Farm Water Branch. Online: [https://www1.agric.gov.ab.ca/\\$Department/deptdocs.nsf/all/irr7401/\\$FILE/alta_irrig_info2017.pdf](https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr7401/$FILE/alta_irrig_info2017.pdf) (accessed 2 Oct 2018).
- Beres, B.L., Bremer, E., Sadasivaiah, R.S., Clarke, J.M., Graf, R.J., McKenzie, R.H., and Dyck, R.J. 2008. Post-emergence application of N fertilizer to improve grain yield and quality of irrigated durum and bread wheat. *Can. J. Plant Sci.* **88**: 509-512.
- Beres, B.L., Graf, R.J., Irvine, R.B., O'Donovan, J.T., Harker, K.N., Johnson, E.N., Brandt, S., Hao, X., Thomas, B.W., Turkington, T.K., and Stevenson, F.C. 2018. Enhanced nitrogen management strategies for winter wheat production in the Canadian prairies. *Can. J. Plant Sci.* **98**: 683-702. [dx.doi.org/10.1139/cjps-2017-0319](https://doi.org/10.1139/cjps-2017-0319).

- Blackshaw, R.E., Hao, X., Brandt, R.N., Clayton, G.W., Harker, K.N., O'Donovan, J.T., Johnson, E.N., and Vera, C.I. 2011. Canola response to ESN and urea in a four-year no-till cropping system. *Agron. J.* **103**(1): 92-99. doi:10.2134/agronj2010.0299.
- Cameron, J.J. Di, H.J., and Moir, J.L. 2013. Nitrogen losses from the soil/plant system: A review. *Ann. Appl. Biol.* **162**: 145-173. doi:10.1111/aab.12014
- Ebrahimian, H., Keshavarz, M.R., and Playan, E. 2014. Surface fertigation: a review, gaps and needs. *Spanish J. Agric. Res.* **12**(3): 820-837. doi: 10.5424/sjar/2014123-5393
- Farm Futures 2018. Fertilizer outlook: Fall fertilizer costs jump higher again. Online: <https://www.farmfutures.com/story-weekly-fertilizer-review-0-30765> (accessed 16 Oct 2018).
- G3 Canada Ltd. 2017. Archived PROs. Online <https://www.g3.ca/archived-pros> (accessed 30 Aug 2017).
- Grant, C.A., Wub, R., Selles, F., Harker, K.N., Clayton, G.W., Bittman, S., Zebarth, B.J., and Lupwayi, N.Z. 2012. Crop yield and nitrogen concentration with controlled release urea and split applications of nitrogen as compared to non-coated urea applied at seeding. *Field Crops Res.* **127**: 170-180. doi: 10.1016/j.fcr.2011.11.002.
- McKenzie, R.H., Bremer, E., Grant, C.A., Johnston, A.M., DeMulder, J., and Middleton, A.B. 2006. In-crop application effect of nitrogen fertilizer on grain protein concentration of spring wheat in the Canadian prairies. *Can. J. Soil Sci.* **86**: 565–572.
- McKenzie, R.H., Kryzanowski, L., and Pauly, D. 2013. Fertilizer Requirements of Irrigated Grain and Oilseed Crops. Agri-Facts, Agdex 100/541-1, Alberta Agriculture and Forestry. Online:

[http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/agdex149/\\$file/100_541-1.pdf?OpenElement](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex149/$file/100_541-1.pdf?OpenElement) (accessed April 9 2018).

- Schwankl, L.J. 2012. Fertigation. Fruit&Nut Research&Information, University of California, Davis. Online <http://fruitsandnuts.ucdavis.edu/files/73697.pdf> (accessed 10 Aug 2017).
- Shoji, S., Delgada, J., Mosier, A., and Miura, Y. 2001. Use of controlled release fertilizers and nitrification inhibitors to increase nitrogen use efficiency and to conserve air and water quality. *Commun. Soil Sci. Plant Anal.* **32**: 1051-1070.
- Smith, E.G., McKenzie, R.H., and Grant, C.A. 2003. Optimal input use when inputs affect price and yield. *Canadian Journal of Agricultural Economics* **51(1)**: 1-13.
- Tran, T.S., and Tremblay, G. 2000. Recovery of ¹⁵N-labelled fertilizer by spring bread wheat at different N rates and application times. *Can. J. Soil Sci.* **80**:533-539.
- Velasco, J.L., Rozas, H.S., Echeverría, H.E., and Barbieri, P.A. 2012. Optimizing fertilizer nitrogen use efficiency by intensively managed spring wheat in humid regions: Effect of split application. *Can. J. Plant Sci.* **92**: 847-856.

Table 1. Mean soil nitrate-N concentrations for wheat and canola areas 2013-2016

Depth (cm)	2013		2014		2015		2016	
	Wheat	Canola	Wheat	Canola	Wheat	Canola	Wheat	Canola
	mg kg ⁻¹							
0-15	3.4	3.5	4.0	4.7	13.3	10.0	9.2	8.9
15-30	5.3	6.5	6.3	7.6	15.8	13.0	6.7	6.4
30-60	5.4	5.6	4.7	6.6	20.8	16.0	3.2	2.8
60-90	4.8	2.7	1.7	4.7	28.8	21.5	1.5	1.5

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Table 2. Growing season (April 1 – September 30) precipitation and irrigation (mm) at Lethbridge 2013-2016.

	2013	2014	2015	2016
Precipitation	389	419	181	285
Irrigation	83	114	196	127
Total	471	533	377	411

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Table 3. Wheat and canola cultivars grown at Lethbridge, 2013-2016.

	2013	2014	2015	2016
Canola	L159	VR9562	VR9562	74-44BL
Wheat	5602HR	WR859CL	Carberry	Carberry

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Table 4. Wheat protein premiums (\$ Mg⁻¹) for average, high and low premium years.

Protein (%)	Premium (\$ Mg ⁻¹)		
	Average	High	Low
>15.24	25.55	85.80	7.05
14.75 – 15.24	19.05	63.90	5.30
14.25 - 14.74	12.55	42.80	3.55
13.75 – 14.24	6.11	21.70	1.78
13.25 - 13.74	0	0	0
12.75 – 13.24	-5.44	-14.06	-1.76
12.25 - 12.74	-10.34	-21.97	-3.53
11.75 - 12.24	-15.25	-29.88	-5.30
<11.75	-20.15	-37.79	-7.07

Sources: AAF 2015a; G3 Canada Ltd. 2017

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Table 5. Machinery and irrigation costs.

Field Operation	Units	Total cost
Swathing - canola	\$ ha ⁻¹	44.48
Swathing - wheat	\$ ha ⁻¹	37.07
Combine	\$ ha ⁻¹	74.13
Harrowing	\$ ha ⁻¹	11.74
Ground sprayer	\$ ha ⁻¹	37.07
Direct seeding	\$ ha ⁻¹	59.30
Hauling	\$ Mg ⁻¹	6.50
Irrigation - wheat	\$ ha ⁻¹	121.44
Irrigation - canola	\$ ha ⁻¹	118.04

Source: AAF 2015d

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Table 6. Statistical results for urea versus ESN™ fertilizer, yield and net return.

Treatment	Yield		Net return	
	Canola	Wheat	Canola	Wheat
Fertilizer form (FF)	0.8378	0.6211	0.9595	0.1017
Fertigation (FN)	0.0003	<.0001	0.8209	0.0108
FF x FN	0.5099	0.9767	0.5099	0.9071

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Table 7. Statistical probabilities for yield and net return by treatment for canola and wheat.

Treatment	Yield		Net return	
	Canola	Wheat	Canola	Wheat
Banded N (BN)	<.0001	<.0001	<.0001	<.0001
Fertigation N (FN)	<.0001	<.0001	0.4092	<.0001
BN x FN	0.0519	0.0181	0.0519	0.3624

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Table 8. Canola yield by banded N rate and fertigation treatment.

Fertigation treatment ^a	Banded N rate (kg ha ⁻¹)				
	0	30	60	90	120
None	2773 <i>cD</i>	3052 <i>cC</i>	3437 <i>bB</i>	3704 <i>aA</i>	3931 <i>aA</i>
4 th Leaf	2998 <i>bcC</i>	3385 <i>abB</i>	3510 <i>bB</i>	3854 <i>aA</i>	4053 <i>aA</i>
Bolting	3047 <i>bD</i>	3430 <i>abC</i>	3663 <i>abBC</i>	3811 <i>aAB</i>	3925 <i>aA</i>
Flowering	2907 <i>bcC</i>	3279 <i>bcB</i>	3506 <i>bB</i>	3771 <i>aA</i>	3954 <i>aA</i>
All	3402 <i>aC</i>	3608 <i>aBC</i>	3834 <i>aAB</i>	3805 <i>aAB</i>	3922 <i>aA</i>

Note: Means within a column not sharing a lowercase italic letter and those with a row not sharing an uppercase italic letter differ significantly at the $p<0.05$ level.

^aFertigation was 30 kg N ha⁻¹ for each of growth stages 4th leaf, Bolting and Flowering, and a total of 90 kg N ha⁻¹ for All as N was applied at each of the three growth stages.

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Table 9. Yield and net return contrasts by total N applied, banded N less banded plus fertigation, canola and wheat.

	Total N applied (kg ha ⁻¹)			
	30	60	90	120
Canola				
Yield contrast	67	72	184	170
Probability	0.514	0.486	0.065	0.088
Net return contrast	36	37	86	80
Probability	0.415	0.390	0.041	0.057
Wheat				
Yield contrast	129	54	-51	-7
Probability	0.300	0.664	0.671	0.955

Note: The contrast was the yield, of net return, with only spring banded N less the yield, or net return, with banded and fertigation applied N that had the same total applied N.

Table 10. Wheat yield by banded N rate and fertigation treatment.

Fertigation treatment ^a	Banded N rate (kg ha ⁻¹)				
	0	30	60	90	120
None	4046 <i>cD</i>	4576 <i>cC</i>	4982 <i>bB</i>	5132 <i>bAB</i>	5346 <i>aA</i>
Tillering	4496 <i>bC</i>	4959 <i>bB</i>	5182 <i>abAB</i>	5295 <i>abA</i>	5416 <i>aA</i>
Flag leaf	4541 <i>bC</i>	4927 <i>bB</i>	5232 <i>abAB</i>	5454 <i>aA</i>	5493 <i>aA</i>
Anthesis	4304 <i>bcD</i>	4897 <i>bC</i>	5126 <i>bBC</i>	5326 <i>abAB</i>	5475 <i>aA</i>
All	5192 <i>aB</i>	5337 <i>aAB</i>	5435 <i>aAB</i>	5486 <i>aAB</i>	5540 <i>aA</i>

Note: Means within a column not sharing a lowercase italic letter and those with a row not sharing an uppercase italic letter differ significantly at the $p<0.05$ level.

^aFertigation was 30 kg N ha⁻¹ for each of growth stages Tillering, Flag leaf, Anthesis, and a total of 90 kg N ha⁻¹ for All as N was applied at each of the three growth stages.

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Table 11. Protein levels of canola and wheat (g kg^{-1}) and canola oil concentration (%) by N source treatment.

	Protein		Oil
	Canola	Wheat	Canola
	(g kg^{-1})	(g kg^{-1})	(%)
Banded N			
0	214.3 <i>c</i>	128.1 <i>d</i>	45.4 <i>a</i>
30	214.5 <i>c</i>	129.0 <i>cd</i>	45.5 <i>a</i>
60	217.5 <i>bc</i>	131.5 <i>c</i>	45.2 <i>ab</i>
90	219.2 <i>ab</i>	136.1 <i>b</i>	45.1 <i>ab</i>
120	223.0 <i>a</i>	140.7 <i>a</i>	44.8 <i>b</i>
Fertigation N ^a			
None	212.8 <i>c</i>	123.9 <i>e</i>	45.8 <i>a</i>
Tillering	216.8 <i>bc</i>	128.2 <i>d</i>	45.1 <i>b</i>
Flag leaf	217.4 <i>b</i>	132.4 <i>c</i>	45.1 <i>b</i>
Anthesis	215.4 <i>bc</i>	137.1 <i>b</i>	45.4 <i>ab</i>
All	226.1 <i>a</i>	143.7 <i>a</i>	44.5 <i>c</i>

Note: Means within a column not sharing a lowercase italic letter differ significantly at the $p < 0.05$ level.

^aFertigation was 30 kg N ha^{-1} for each of growth stages Tillering (4th Leaf), Flag leaf (Bolting), Anthesis (Flowering), and a total of 90 kg N ha^{-1} for All as N was applied at each of the three growth stages.

Table 12. Canola net return (\$ ha⁻¹) by fertigation treatment and banded N rate.

Fertigation treatment ^a	Banded N rate (kg ha ⁻¹)				
	0	30	60	90	120
None	474 <i>bC</i>	551 <i>bC</i>	672 <i>aB</i>	743 <i>abAB</i>	752 <i>aA</i>
4 th Leaf	521 <i>abD</i>	643 <i>abC</i>	654 <i>aBC</i>	758 <i>aAB</i>	756 <i>aA</i>
Bolting	542 <i>abB</i>	662 <i>aA</i>	718 <i>aA</i>	740 <i>abA</i>	747 <i>abA</i>
Flowering	483 <i>bC</i>	598 <i>abB</i>	653 <i>aAB</i>	723 <i>abA</i>	759 <i>abA</i>
All	604 <i>aA</i>	650 <i>abA</i>	704 <i>aA</i>	651 <i>bA</i>	659 <i>bA</i>

Note: Means within a column not sharing a lowercase italic letter and those with a row not sharing an uppercase italic letter differ significantly at the $p<0.05$ level.

^aFertigation was 30 kg N ha⁻¹ for each of growth stages 4th leaf, Bolting and Flowering, and a total of 90 kg N ha⁻¹ for All as N was applied at each of the three growth stages.

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Table 13. Wheat price (\$ Mg⁻¹) and net return (\$ ha⁻¹) by protein premium and by spring banded N rate.

N rate	Base premium		High premium		Low premium		No premium
	Price	Return	Price	Return	Price	Return	Return
0	201 <i>d</i>	270 <i>c</i>	202 <i>d</i>	276 <i>d</i>	204 <i>d</i>	280 <i>b</i>	288 <i>c</i>
30	202 <i>d</i>	312 <i>b</i>	204 <i>cd</i>	322 <i>cd</i>	204 <i>cd</i>	324 <i>a</i>	332 <i>ab</i>
60	204 <i>c</i>	332 <i>ab</i>	210 <i>c</i>	361 <i>bc</i>	205 <i>c</i>	336 <i>a</i>	341 <i>a</i>
90	208 <i>b</i>	339 <i>ab</i>	220 <i>b</i>	397 <i>b</i>	206 <i>b</i>	330 <i>a</i>	330 <i>ab</i>
120	213 <i>a</i>	348 <i>a</i>	233 <i>a</i>	444 <i>a</i>	208 <i>a</i>	321 <i>a</i>	312 <i>bc</i>

Note: Means within a column not sharing a lowercase italic letter differ significantly at the $p < 0.05$ level.

Table 14. Wheat price (\$ Mg⁻¹) and net return (\$ ha⁻¹) by protein premium and by fertigation treatment.

Fertigation ^a	Base premium		High premium		Low premium		No premium
	Price	Return	Price	Return	Price	Return	Return
None	197 ^e	284 ^c	193 ^e	263 ^d	203 ^e	308 ^a	322 ^{ab}
Tillering	201 ^d	302 ^{bc}	201 ^d	310 ^{cd}	204 ^d	316 ^a	324 ^{ab}
Flag leaf	204 ^c	330 ^{ab}	209 ^c	356 ^{bc}	205 ^c	333 ^a	337 ^a
Anthesis	209 ^b	329 ^{ab}	223 ^b	385 ^b	207 ^b	318 ^a	316 ^{ab}
All stages	216 ^a	356 ^a	243 ^a	486 ^a	209 ^a	318 ^a	303 ^b

Note: Means within a column not sharing a lowercase italic letter differ significantly at the $p<0.05$ level.

^aFertigation was 30 kg N ha⁻¹ for each of growth stages Tillering, Flag leaf and Anthesis, and a total of 90 kg N ha⁻¹ for All as N was applied at each of the three growth stages