2021 Final Report

for the

Saskatchewan Ministry of Agriculture's

Agricultural Demonstration of Practices & Technologies (ADOPT) Program

and Fertilizer Canada

Project Title: Winter Wheat Response to Nitrogen Fertilizer Placement and Timing Options

(Project #20200436)

Principal Applicant: Chris Holzapfel, MSc, PAg

Indian Head Agricultural Research Foundation, PO BOX 156, Indian Head, SK, S0G 2K0

Correspondence: cholzapfel@iharf.ca or (306) 695-7761

Project Identification

1. **Project Title:** Winter wheat response to contrasting nitrogen fertilizer placement and timing options
2. **Project Number:** 20200436
3. **Producer Group Sponsoring the Project:** Indian Head Agricultural Research Foundation
4. **Project Location(s):** Indian Head, Saskatchewan, R.M. #156
5. **Project start and end dates(s):** September-2020 to February-2022
6. **Project contact person & contact details:**

Chris Holzapfel, Research Manager
Indian Head Agricultural Research Foundation
PO BOX 156, Indian Head, SK, S0G 2K0
Mobile: 306-695-7761
Office: 306-695-4200
Email: cholzapfel@iharf.ca

Objectives and Rationale

7. **Project Objectives:**

Developing Best Management Practices (BMPs) for nutrient applications has long been focussed on the 4R principles which refer to using the: 1) right source, 2) right rate, 3) right time and 4) right placement. This creates unique challenges for winter cereals since the growing season is much longer than for spring seeded crops and crop requirements for nitrogen (N) are small for the 8- to 9-month period after seeding. Consequently, and especially considering that establishment of winter cereals can be unpredictable, it is often recommended that N fertilizer applications be split between fall side- or mid-row band applications and an early-spring surface broadcast application. This results in extra cost and labour for producers but reduces many of the risks associated with applying the entire N requirements either during seeding or in the early-spring. Consequently, split-applications of N fertilizer tend to perform consistently well when averaged over multiple seasons and a range of environmental conditions.

The objective of this project was to demonstrate winter wheat responses to N rate when all the N was applied as untreated urea either in a sideband, early-spring broadcast, or a split-application with 50% of the N side-banded and the remainder as an early-spring broadcast application. While the N form was not varied in this demonstration and enhanced efficiency N products can be a good fit with winter cereals, urea is dominant N source in western Canada and an appropriate choice to demonstrate fundamental differences amongst the timing/placement options.

8. **Project Rationale:**

In order to minimize potential N fertilizer losses due to leaching and denitrification, the historical recommendation for winter wheat in southeast Saskatchewan has been to broadcast most of the crop's N fertilizer requirements early in the spring. However, the preferred product, ammonium nitrate (34-0-0), has not been available to purchase in bulk quantities for many years and producers have been forced to use other options. These include urea, which is less suitable for surface applications, or enhanced efficiency fertilizer (EEF) products which can reduce potential losses but also increase input costs and may not provide consistent benefits depending on the specific conditions encountered. Liquid UAN is a popular choice for spring applications because it can be applied with a field sprayer and contains 25% NO_3-N which is not prone to volatilization; however, the NO_3-N is susceptible to leaching and denitrification which makes UAN a comparatively poor option for fall applications.

Especially considering that urea is not ideal for broadcast applications and there is extra cost associated with spring applications, there is incentive to simply band the crop's entire N fertilizer requirements of winter cereals during seeding. This practice is operationally easiest for most farmers and, in many cases, the reduced potential for volatilization with in-soil banding can offset the higher potential for leaching or denitrification losses with fall applications. On the other hand, depending when seeding is completed and the actual fall weather, applying high rates of N in the fall can cause excessive vegetative growth which may reduce winter hardiness along with N supply the following spring when it is needed most. Furthermore, establishment of winter wheat is not always successful, especially if fall conditions are dry; therefore, many growers are hesitant to commit their entire N budget prior to assessing crop condition in the early-spring. Generally, side-banding a large proportion of the N works well when later seeding is combined with cool, dry conditions but can be risky in warmer, wetter regions where it is advisable to reserve much of the N until early-spring. This is especially true in fields (or parts of the field) that are poorly drained and frequently accumulate excess moisture during heavy precipitation events or the spring snow-melt period.

Deferring a large percentage of the N requirements until spring also has inherent risks, particularly if the following spring is dry or the fertilizer application is delayed. Regardless of the form, N fertilizer needs precipitation to move it into the rooting zone before it can be fully utilized by crops. If this does not occur soon enough in the spring after the fertilizer is applied, early N deficiencies can lead to irreversible yield loss. Furthermore, dry conditions after application of untreated urea often increase the potential for NH_3 volatilization, a permanent loss which results in lower use-efficiency of the applied N. Although spring, surface-applied N tends to be more effective in wetter environments, when it is too wet, growers can have difficulty accessing fields to apply the fertilizer in a timely manner. This also has potential to result in early season deficiencies, particularly if not enough N was applied the previous fall.

Due to all of these factors, split-applications are often considered the least risky option over the long-term and for a broad range of conditions. The premise is to apply enough N up front to carry the crop through the fall/early-spring and top up the remainder closer to when the crop will require it. The latter occurs after growers can confirm that the crop has been successfully established and when the high-risk spring thaw period in the late winter/ early-spring has passed.

Methodology and Results

9. Methodology:

A field trial with winter wheat was initiated in 2018-19 and repeated the following two seasons (2019-20 and 2020-21). The treatments were a factorial combination of three N fertilizer placement/timing strategies (100% sideband, 100% early-spring broadcast, 50:50 split-application) and five N fertilizer rates (60, 90, 120, 150, and 180 kg N/ha). A control treatment where the only N fertilizer applied was 7 kg N/ha from seed-placed monoammonium phosphate (11-52-0) was also included. In 2020-21, an additional treatment was included where, as an early-spring broadcast, we applied 120 kg N/ha of urea treated with N- (n-butyl) thiophosphoric triamide (NBPT), a urease inhibitor which reduces the risk of volatilization losses. The N fertilizer rates were adjusted for residual soil NO_3-N and the treatments (Table 1) were arranged in a four replicate RCBD.

Table 1. Winter wheat nitrogen fertilizer management by rate treatments

#	Timing / Placement	Total N Rate ^{Z}
1	N/A	7 kg N/ha ^{Y} + residual
2	Side-Band	60 kg N/ha
3	Side-Band	90 kg N/ha
4	Side-Band	120 kg N/ha
5	Side-Band	150 kg N/ha
6	Side-Band	180 kg N/ha
7	Spring Broadcast	60 kg N/ha
8	Spring Broadcast	90 kg N/ha
9	Spring Broadcast	120 kg N/ha
10	Spring Broadcast	150 kg N/ha
11	Spring Broadcast	180 kg N/ha
12	Split-application (50/50)	60 kg N/ha
13	Split-application	90 kg N/ha
14	Split-application	120 kg N/ha
15	Split-application	150 kg N/ha
16	Split-application	180 kg N/ha

^{Z} Includes Residual NO_3-N (0-60 cm) based on fall composite soil samples
^{Y} Provided by seed-placed 11-52-0 for all treatments

In each of the three years, the plots were seeded into canola stubble using an eight-opener SeedMaster drill where the side-banded fertilizer is placed approximately 3.7 cm (1.5”) beside and 1.8 cm (0.75”) below the seed-row. With a target seed depth of approximately 1.8 cm (0.75”) this resulted in a side-banded fertilizer depth of approximately 3.7 cm (1.5”). Seeding was completed September 18-24, depending on the year (Table 2). The early-spring broadcast treatments were applied in on April 16 in 2019, April 30 in 2020, and May 8 in 2021. The variety used in all three years was CDC Goldrush and the seeding rate was 400 seeds/m^2. Weeds were controlled using registered pre-harvest and in-crop herbicides, fungicides were applied preventatively at approximately 50% anthesis, and no insecticides were required. The centre five rows of each plot were straight-combined when the crop was mature and fit for harvest with harvest dates ranging from August 16 to September 1. Grain yields were determined from the harvested plot areas and are adjusted for dockage and to 14.5% seed moisture content. Grain protein was determined using a FOSS NIR instrument and are the average of two samples per plot. Weather data were compiled from a nearby Environment and Climate Change Canada station.

Response data from all three seasons were combined prior to analyses and analyzed using the generalized linear mixed model (GLIMMIX) procedure in SAS® Studio. The effects of Year (Yr), N timing/placement (TP), N rate (NR), and all possible interactions were treated as fixed while replicate effects (within years) were considered random. Heterogeneity in variance component estimates between years was tested for with both yield and protein; however, the more complex analyses did not improve the model fit in any cases. The unfertilized control plots were incorporated into orthogonal contrasts but removed for the factorial analyses. The orthogonal contrasts were used to test whether responses to NR were linear, quadratic (curvilinear), or not significant. A second, smaller dataset was analyzed to compare the spring broadcast application of 120 kg N/ha as NBPT treated urea to untreated urea applied at the same rate and using the same timing/placement options (2021 only). Treatment effects and differences between means were considered significant at $P \leq 0.05$ and the conservative Tukey-Kramer test was used means separations.

Table 2. Selected agronomic information and dates of operations for winter wheat nitrogen demonstrations at Indian Head in 2018-19, 2019-20, and 2020-21.

Factor / Field Operation	2018-19	2019-20	2020-21
Previous Crop	Canola	Canola	Canola
Pre-emergent herbicide	894 g glyphosate/ha + 5 g florasulam/ha Sep-27-2018	894 g glyphosate/ha + 5 g florasulam/ha Sep-26-2019	894 g glyphosate/ha + 5 g florasulam/ha Sep-25-2020
Seeding Date	Sep-21-2018	Sep-24-2019	Sep-18-2020
Seed Rate	400 seeds/m^2 (137 kg/ha)	400 seeds/m^2 (145 kg/ha)	400 seeds/m^2 (123 kg/ha)
kg P_2O_5-K_2O-S ha^{-1}	35-0-0	35-0-0	35-0-0
N Broadcast Applications	Apr-16-2019	Apr-30-2020	May 8-2021
In-crop Herbicide	560 g MCPA ester/ha + 100 g clopyralid/ha + 15 g pyroxsulam/ha Jun-10-2019	560 g MCPA ester/ha + 100 g clopyralid/ha + 15 g pyroxsulam/ha Jun-5-2020	501 g MCPA ester/ha +129 g fluroxypyr/ha + 90 g clopyralid/ha + 15 g pyroxsulam/ha Jun-12-2021
Foliar Fungicide	100 g prothioconazole/ha + 100 g tebuconazole/ha Jul-1-2019	100 g prothioconazole/ha + 100 g tebuconazole/ha Jul-3-2020	100 g prothioconazole/ha + 100 g tebuconazole/ha Jul-6-2021
Pre-harvest herbicide	894 g glyphosate/ha Aug-8-2019	894 g glyphosate/ha Aug-6-2020	894 g glyphosate/ha Aug-17-2021
Harvest date	Aug-16-2019	Aug-17-2020	Sep-1-2021

10. Results:

Growing season weather and residual soil nutrients

Growing season weather data for each of the three growing seasons is presented alongside the long-term averages in Table 3. The trial sites were always well-drained without much potential for water to accumulate during heavy rainfall events or the spring snow melt. As such, it was unlikely for the soils to be saturated for extended periods and the potential for denitrification or leaching losses of N fertilizer was relatively low. The fall of 2018 was cool with approximately normal precipitation while, for the following spring-summer, temperatures were slightly below the long-term average and precipitation totals (April through July) were 66% of average. In the fall of 2019, September was warm and wet but October was cool and comparatively dry. The following spring/summer was similar to the previous season with slightly below normal temperatures and only 51% of the long-term average precipitation from April through July. For the final season (2020-21), fall temperatures were close to normal but it was extremely dry with low soil moisture reserves following the 2020 crop and less than 20 mm of cumulative precipitation in September and October. In contrast to the previous years, the 2021 season (April through July) was slightly warmer than average with close to normal precipitation; however, the dry fall combined with relatively little precipitation in April or early May resulted in poor establishment. Due to variation in spring weather and crop stages, the timing of the spring broadcast N applications ranged from April 16 (2019) to May 8 (2021); however, in all cases, precipitation was received within a reasonable time-frame to start moving the applied N into the rooting zone and reduce the potential for volatilization losses. For the 2018-19 crop, 15 mm of precipitation was received within 24 hours of the spring N applications. The following season, 12 mm of precipitation was received within 24 hours of the applications and an additional 10 mm fell within the next 9 days. For the 2020-21 crop, conditions were extremely dry at the time of application and for the immediate period that followed; however, 80 mm of precipitation fell within 16 days of the spring broadcast applications and conditions leading up to this event were not conducive to high losses of N. Overall, the environmental conditions over the three growing seasons were not particularly favourable for winter wheat production and the risk of environmental losses of N applied as fertilizer was also relatively low, regardless of the timing or method of application.

Table 3. Mean monthly temperatures and precipitation amounts along with long-term (1981-2010) averages for the 2019, 2020, and 2021 growing seasons at Indian Head, SK. The growing season was April through July and data for the fall period (September through October) were also reported.

Year	Prev. Sep	Prev. Oct	April	May	June	July	Apr-July
	---------- Mean Temperature (°C) ----------						
2019	7.6	1.3	3.9	8.9	15.7	17.4	11.5 (94%)
2020	11.9	1.0	0.3	10.7	15.6	18.4	11.3 (92%)
2021	11.5	1.4	3.3	9.0	17.7	20.3	12.6 (102%)
LT	11.5	4.0	4.2	10.8	15.8	18.2	12.3
	---------- Total Precipitation (mm) ----------						
2019	39.6	25.5	25.3	13.3	50.4	53.1	142 (66%)
2020	120.8	10.9	22.0	27.3	23.5	37.7	111 (51%)
2021	15.0	3.8	14.9	81.6	62.9	51.2	211 (98%)
LT	35.3	24.9	22.6	51.8	77.4	63.8	216

Soil test results were based on composite samples collected each fall and used for both adjusting N rates and providing general background information (Table 4) . The trial sites were within approximately 2 km of each other over the three years and the overall soil characteristics were similar. The soil is classified as an Indian Head heavy clay with pH ranging from 7.8-8.0 (0-15 cm), organic matter from 4.6-5.4%, and residual NO_3-N ranging from 9-16 kg NO_3-N/ha (0-60 cm). Residual phosphorus was consistently low while potassium and sulfur levels were relatively high.

Table 4. Soil test results for winter wheat demonstrations over three seasons at Indian Head, Saskatchewan.

Year	Depth (cm)	pH	S.O.M. (%)	NO_3-N (kg/ha)	Olsen-P (ppm)	K (ppm)	S (kg/ha)
2018-19	0-15	7.8	5.4	5	3	436	22
	15-60	8.1	–	7	–	–	34
	0-60	–	–	12	–	–	56
2019-20	0-15	7.9	4.6	6	2	516	11
	15-60	8.2	–	3	–	–	27
	0-60	–	–	9	–	–	38
2020-21	0-15	8.0	4.8	6	2	567	27
	15-60	8.2	–	10	–	–	34
	0-60	–	–	16	–	–	61

Crop Responses to Nitrogen Management Strategies and Rates

Many of the detailed results tables are reserved for the Appendices but will be referred to as necessary. Results of the overall F-tests are presented in Table 5 below. The main effect of Year (Yr) was significant for both grain yield (P = 0.002) and protein (P < 0.001); thus, indicating that these variables differed from one season to the next when averaged across treatments. The main effect of N fertilizer timing/placement (TP) was only marginally significant for yield (P = 0.086) but the Yr x TP effect (P < 0.001) indicated that the responses differed from year-to-year. The N rate (NR) effect for yield was highly significant (P < 0.001) when averaged across TP methods but, again, the response varied over the three-year period (P < 0.001). The lack of TP x NR (P = 0.206) or Yr x N x TP interactions (P = 0.939) indicated that the observed yield responses to N rate were similar amongst timing/placement options both within and across years. For grain protein, the effects of N timing/placement (P = 0.017), N rate (P < 0.001), and their interaction (TP x NR; P = 0.033) were all significant. Interactions between each of the main effects and year were also highly significant for grain protein (P < 0.001); however, the three-way (Yr x TP x NR) interaction was not (P = 0.510). Because grain yield and protein concentrations are often closely correlated, they will be discussed together as much as possible.

Table 5. Model fit statistics and tests of fixed effects for winter wheat yield and grain protein. The unfertilized control treatment was excluded so that the data could be analysed as a factorial. Heterogeneous estimates of variance components (between years) were permitted but the more complex model was only utilized if doing so improved the model fit.

Variance Components	**Yield (kg/ha)**	**Protein (%)**
(between years)	------------------------- AICc [Z] (smaller is better)	-------------------------
Homogeneous	1903.2	165.9
Heterogeneous	1905.5	170.1
Source	----------------------------------- p-values	-----------------------------------
Year (Yr)	0.002	<0.001
Time/Place (TP)	0.086	0.017
N Rate (NR)	<0.001	<0.001
TP x NR	0.206	0.033
Yr x TP	<0.001	<0.001
Yr x NR	<0.001	<0.001
Yr x TP x NR	0.939	0.510

[Z] Akaike information criterion – used to determine the most appropriate model for each response variable

The TP effects on yield for individual years and averaged across years are presented both in Fig. 1 below and Table 6 of the Appendices while the effects on protein are presented in Fig. 2 and Table 9. In 2018-19, winter wheat yields were similar in 2018-19 (3793-3825 kg/ha), regardless of the timing or placement method by which the N fertilizer was applied. Similarly, grain protein concentrations were also statistically similar across TP options (12.6-12.9%); however, the tendency was for slightly lower protein when all of the N was side-banded during seeding as opposed to broadcast in the spring. In 2019-20, where there was adequate fall moisture but the following spring was dry, the highest yields were achieved when all of the N was side-banded (4287 kg/ha) and lowest yields occurred when all of the N was broadcast in the spring (3952 kg/ha). Yields were intermediate with the split-application. In contrast, N timing/placement effects on protein were such that the lowest protein occurred with side-banding, the highest occurred with spring broadcasting, and, again, values were intermediate with the split-application. This suggests that the spring broadcast N was not available early enough to prevent slight yield losses in 2019-20 but did contribute to higher grain protein. For the winter wheat in 2020-21, both grain yields and protein concentrations were statistically similar for all three of the N fertilizer timing/placement (TP) options. When averaged over the three-year period, grain yields were statistically similar, regardless of the N application timing or placement method (Table 6); however, protein was slightly higher with the early-spring broadcast N compared to the side-band or split applications (Table 9).

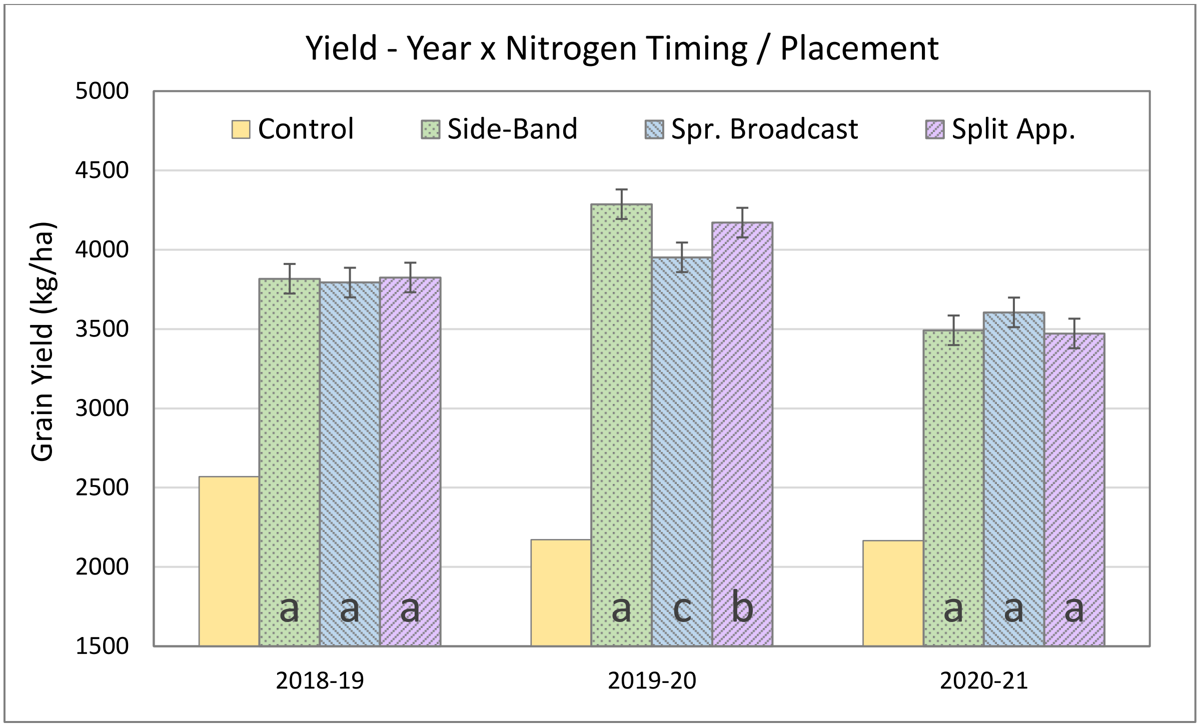

Figure 1. Winter wheat yield response to timing and placement of nitrogen (N) at Indian Head in 2019, 2020, and 2021. Error bars are the standard error of the treatment means. The unfertilized control treatments are included for information purposes but were not incorporated into the statistical analyses.

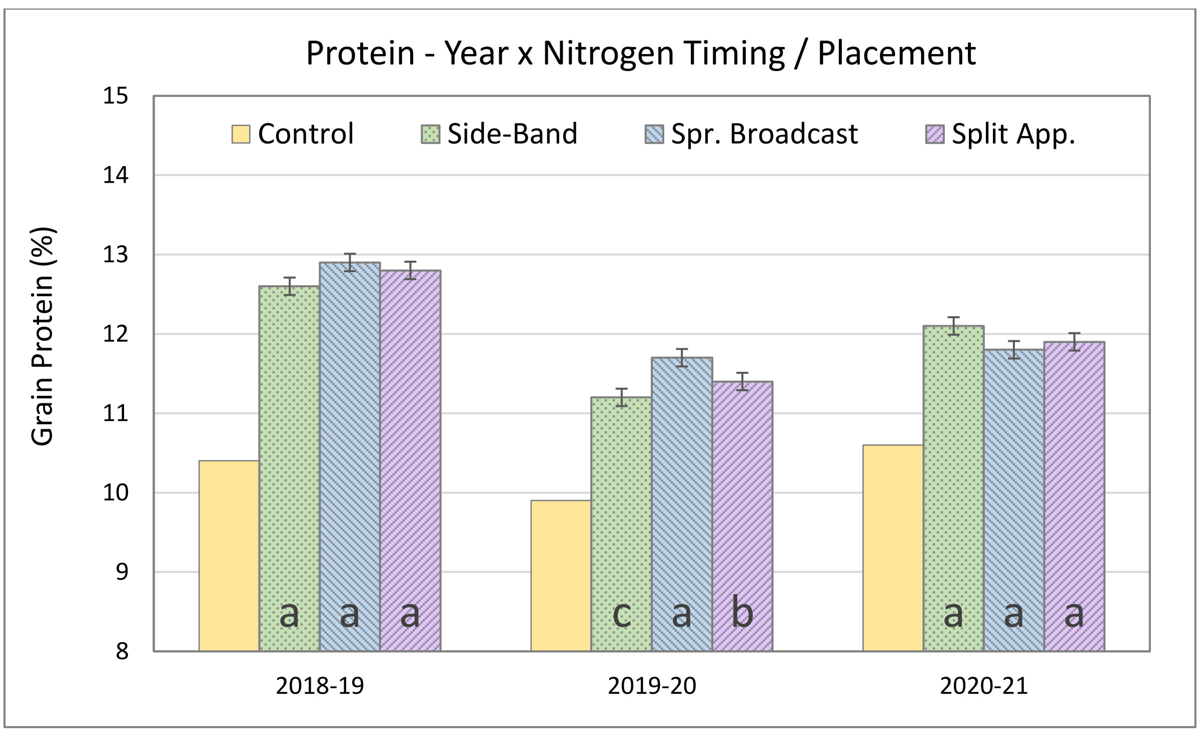

Figure 2. Winter wheat protein response to timing and placement of nitrogen (N) at Indian Head in 2019, 2020, and 2021. Error bars are the standard error of the treatment means. The unfertilized control treatments are included for information purposes but were not incorporated into the statistical analyses.

The N rate (NR) effects on yield are presented in Fig. 3 and Table 7 while effects on protein are in Fig. 4 and Table 8. Due to greater yield increases at the lower end of the range and diminishing returns to increasing N at the higher rates, the responses to N rate were quadratic, or curvilinear for all three years (*P* < 0.001). Despite slightly lower yields in 2020-21, the shape of the response was similar in 2018-19 and 2020-21 whereby yields began leveling off at approximately 120 kg N/ha (residual soil NO_3-N plus fertilizer). In 2019-20, under higher yielding conditions, the crop responded to higher rates of N with yields only beginning to level off at 150 kg N/ha (residual soil NO_3-N plus fertilizer). As expected, grain protein concentrations also increased with N fertilizer rate but the specific nature of the response varied from year-to-year. In 2018-19, the response was quadratic (*P* = 0.004) and shaped similar to the yield response curve, but continued increasing at comparatively higher N rates, only appearing to start diminishing at approximately 180 kg N/ha (Table 10). In 2020-21, where we saw the sharpest yield increases with N fertilization, grain protein was relatively stable up to 90 kg N/ha but then began to increase rapidly with further increases in N rate. Similar to the previous season, this also resulted in a quadratic response (*P* < 0.001); however, the shape of the response curve differed compared to the previous year and what was observed for yield. The relatively small effect on protein at lower N levels in 2019-20 was attributed to dilution as yields were rapidly increasing as N was increased at these lower rates. In 2020-21, the protein response was not quadratic at the desired probability level (*P* = 0.089) and, as such, was treated as linear. In this case, protein increased steadily and consistently from the lowest to the highest N rates.

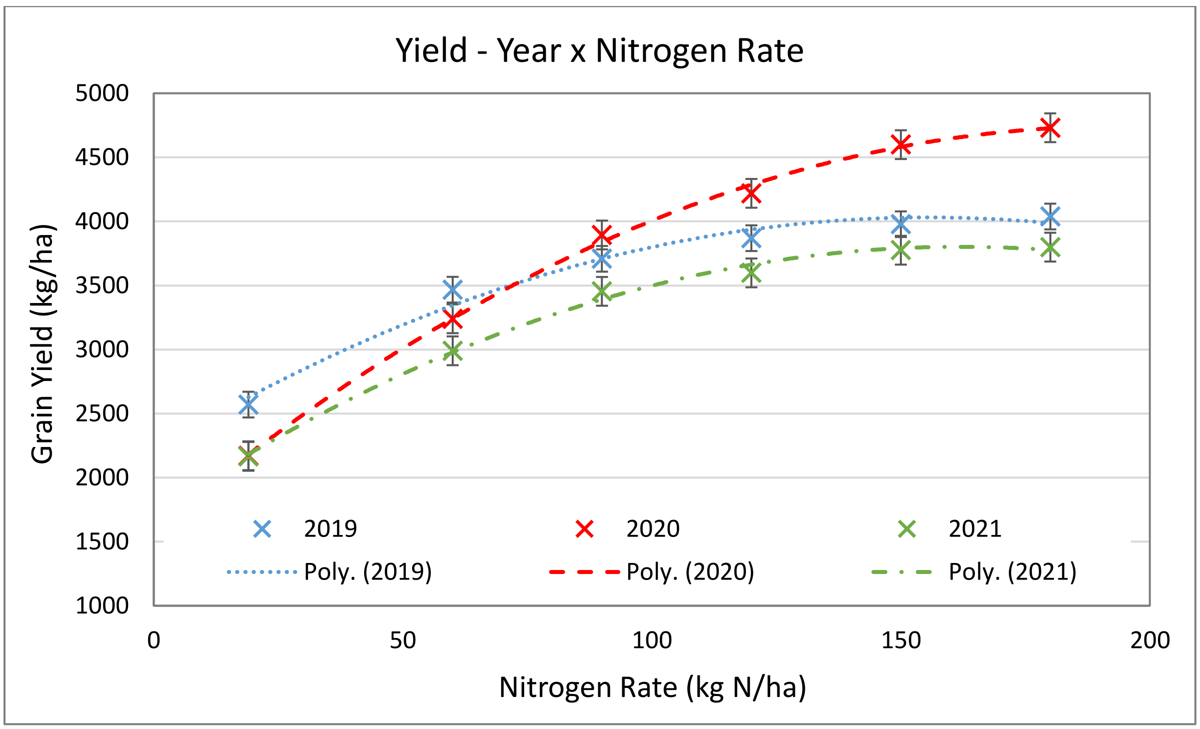

Figure 3. Winter wheat yield response to nitrogen (N) rate at Indian Head in 2019, 2020, and 2021. The N rates include fertilizer plus residual soil N which averaged 12 kg NO_3-N/ha over the three years. Error bars are the standard error of the treatment means.

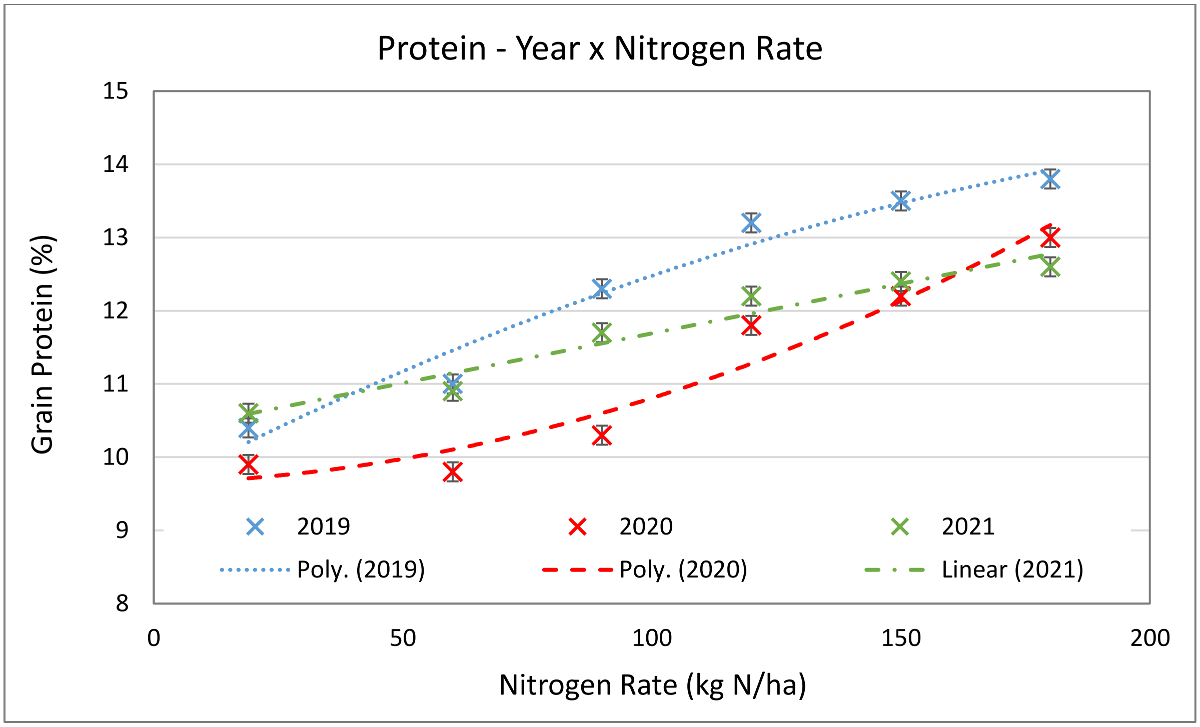

Figure 4. Winter wheat protein response to nitrogen (N) rate at Indian Head in 2019, 2020, and 2021. The N rates include fertilizer plus residual soil N which averaged 12 kg NO_3-N/ha over the three years. Error bars are the standard error of the treatment means.

Treatment means and orthogonal contrast results for the TP x NR interactions are presented in Fig. 5-6 below and Tables 8 and 11 for yield and protein, respectively. Again, this interaction was not significant for grain yield (*P* = 0.206) and we can see that the average yield responses (across years) to N rate are very similar, regardless of how or when the fertilizer was applied. In contrast, the TP x NR effect was significant for protein (*P* = 0.033); however, the nature of this interaction was subtle. When averaged over the three seasons, the response to N rate was linear (*P* < 0.001) but not quadratic, for all three TP methods (*P* = 0.191-0.730). Further to this, the observed protein values at any individual N rate did not significantly differ, regardless of either the rate or method of application. The interaction was likely due to subtle variation in the relative rankings of the TP options within individual rates and differences in the slope of the response whereby the steepest protein response occurred with spring broadcast N and the shallowest occurred with side-banding. In other words, spring broadcast N was slightly more efficient at building protein than the side-banded N; however, side-banded N was occasionally more efficient for building yield. Again, despite its statistical significance, this interaction was subtle and the Yr x TP x NR interaction was not significant for either yield (*P* = 0.939) or protein (*P* = 0.510). Despite the lack of any three-way interactions, individual treatment means are presented for each growing season in Table 8 (yield), Table 11 (protein), and in Figs. 5-10 of the Appendices.

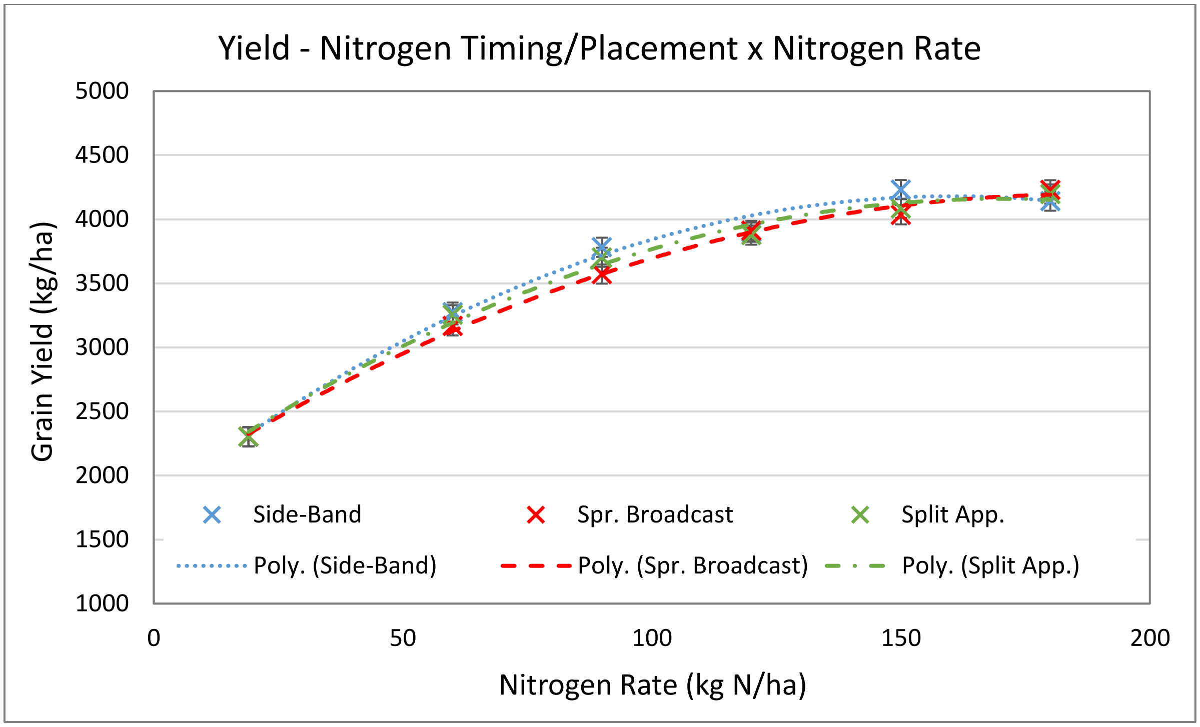

Figure 5. Winter wheat yield response to varying rates of side-banded, spring broadcast, or split-applied nitrogen (N) at Indian Head, averaged over three years. The N rates include fertilizer plus soil N which averaged 12 kg NO_3-N/ha over the three years. Error bars are the standard error of the treatment means.

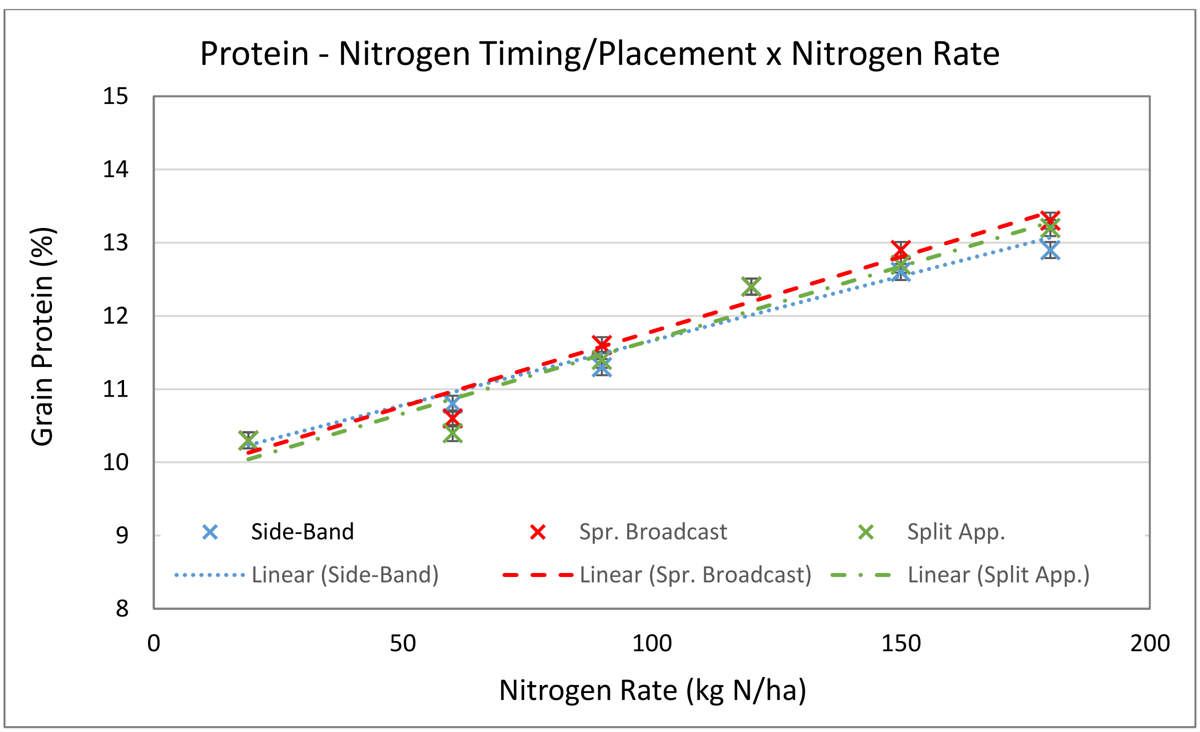

Figure 6. Winter wheat protein response to varying rates of side-banded, spring broadcast, or split-applied nitrogen (N) at Indian Head, averaged over three years. The N rates include fertilizer plus soil N which averaged 12 kg NO_3-N/ha over the three years. Error bars are the standard error of the treatment means.

In 2020-21 only, an additional treatment was included where the 120 kg N/ha rate of spring broadcast (untreated) urea was replaced with N- (n-butyl) thiophosphoric triamide (NBPT) treated urea. While NBPT slows the hydrolysis of urea, thereby reducing the potential for volatilization losses of surface applied N, there was no benefit to using it with respect to either yield or protein under the environmental conditions encountered (Table 12). We speculate that, regardless of form, volatile losses of the spring broadcast N were negligible with extremely dry and relatively cool conditions immediately following the surface applications and nearly 50 mm of precipitation to move the N into the rooting zone starting at approximately 12 days after application. Again, establishment was poor in 2020-21 and there was very little growth or crop demand for N in the fall or early-spring. The strong overall responses to spring broadcast N that were observed in 2020-21 support this conclusion. It should be acknowledged that the use of NBPT treated urea can greatly reduce the risk of volatilization losses associated with surface applied N; however, adequate precipitation is still required to move the N into the rooting zone where it can be taken up and utilized by the crop.

Extension Activities

This project was discussed, and the plots were toured by approximately 125 guests at the Indian Head Crop Management Field Day on July 16, 2019. In addition to Chris Holzapfel introducing the project and discussing the specific objectives, Dan Heaney with Fertilizer Canada led a broader discussion on 4R N management principles as they pertain to western Canadian crop production. The plots were also visited on July 12 during a tour for approximately 60 Federated Co-operatives Limited (FCL) agronomists from throughout the province. Chris Holzapfel presented highlights from the project at an Independent Consulting Agronomists Network (ICAN) meeting in Regina (Feb. 4) and the IHARF Winter Meeting and AGM in Balgonie (Feb. 5) with an estimated combined attendance of 175-200 people. Due to COVID-19 restrictions, we were not able to show the field trials during any summer field tours or workshops in 2020; however, highlights from the project were shared at the 2020 Manitoba Agronomists Conference (virtual, December 16-17, 2020, approximately 350 attendees) and IHARF's Soil and Crop Management Seminar/AGM (virtual, February 3, 2021, approximately 170 attendees). In 2020-21, the plots were shown to approximately 70 participants on July 20 during a scaled back IHARF Crop Management Field Day where there was an discussion of N management in winter wheat and broader considerations regarding adaption and establishment issues under the recent dry conditions. Final results will continue to be presented where appropriate through oral presentations and other extension materials in the winter of 2020-21 and beyond. This final technical report, past interim reports, and other extension materials will be available online through IHARF and/or Agri-ARM websites.

11. Conclusions and Recommendations

This project has demonstrated winter wheat response to fundamentally different N management strategies and a wide-range of rates. Under the conditions encountered, the optimal N rate for maximizing yield was 120-150 kg N/ha (fertilizer plus soil residual) with a stronger response in 2019-20 compared to either 2018-19 or 2020-21. As expected, protein generally peaked at higher N rates than yield; but, the economic merits of fertilizing for maximum protein will depend on where the grain is marketed and whether any premiums/discounts are in effect. In general, the potential for N losses due to denitrification or leaching with fall-applied N was low with relatively late seeding, dry weather, and well-drained sites in all three seasons. Focussing on the spring broadcast treatments, conditions were dry overall but precipitation always occurred within a reasonable time-frame which helped to mitigate volatile losses of the surface applied N and move it into the rooting zone where it would be relatively protected against losses and available to the crop. All factors considered, each of the N timing/placement strategies performed reasonably well; however, split-applications can provide greater flexibility in terms of allowing crop establishment to be assessed before committing the full N requirements of the winter wheat while also buffering against potential environmental N losses and early-season N deficiencies. That said, the added cost of two-pass seeding/fertilization systems and logistic considerations must also be considered. Applying N sufficiently early in the spring can be a challenge in western Canada, particularly in wet springs, and there is also a risk of this N being stranded near the soil surface if timely precipitation after the application does not occur. Side-banded N is safest with later seeding (due to cooler soils and less fall crop growth) is combined with relatively dry/cool weather and well-drained fields. Deferring at least some of the crop's N requirements until spring is increasingly recommended if seeding occurs relatively early or in regions that are, in general, warmer and wetter. Although our results show that doing so can perform reasonably well, deferring all of a winter cereal crop's N fertilizer requirements until spring is generally not recommended unless, perhaps, residual soil N levels are unusually high or relatively large quantities of N are provided with phosphorus and/or sulfur fertilizer products. It would have been ideal to conduct this work under wetter conditions with higher yield potential and greater risk of environmental N losses; however, we speculate that such conditions would have favoured the split- or spring broadcast applications to a greater extent. Similarly, scaling this work up to whole fields, which are often more variable and may include poorly-drained areas where standing water can occasionally occur, would likely favour split-applications over either banding all of the N during seeding or waiting until things dry up enough to broadcast it all in the early-spring.

<u>Supporting Information</u>

12. Acknowledgements:

This project was jointly funded by Fertilizer Canada and the Agricultural Demonstration of Practices and Technologies (ADOPT) initiative under the Canadian Agricultural Partnership bi-lateral agreement between the federal government and the Saskatchewan Ministry of Agriculture. IHARF has a strong working relationship and a memorandum of understanding with Agriculture and Agri-Food Canada which should be acknowledged and IHARF provided the land, equipment, and infrastructure required to complete this project. Certain crop protection products were provided in-kind by Corteva and Bayer CropScience while the seed was provided by McDougal Acres Ltd. Special thanks are extended to all of the IHARF staff who worked on the field trials and harvest samples over the three seasons and to Danny Petty for administering the project.

13. Appendices:

Table 6. Main effect means for average N timing/placement (TP) effects on winter wheat yield. Means within a group (Yr x TP; TP) followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Treatment	2018-19	2019-20	2020-21	Average
	Grain Yield (kg/ha)			
Control	2570	2171	2166	2302
Side-Banded	3817 a	4287 a	3492 a	3865 A
Spr. Broadcast	3793 a	3952 c	3605 a	3783 A
50:50 Split App.	3825 a	4171 b	3472 a	3823 A
S.E.M.		93.3		53.9

Table 7. Main effect means and orthogonal contrast results for average N rate (NR) effects on winter wheat grain yield. Means within a group (Yr x NR; NR) followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Treatment	2018-19	2019-20	2020-21	Average
	Grain Yield (kg/ha)			
Control	2570	2171	2166	2302
60 kg N/ha	3467 c	3240 d	2990 c	3232 D
90 kg N/ha	3708 bc	3894 c	3454 b	3685 C
120 kg N/ha	3869 ab	4219 b	3598 ab	3896 B
150 kg N/ha	3978 ab	4599 a	3775 a	4117 A
180 kg N/ha	4038 a	4731 a	3799 a	4189 A
S.E.M.		100.3		57.9
	p-value			
NR – linear	<0.001	<0.001	<0.001	<0.001
NR – quad	<0.001	<0.001	<0.001	<0.001

Table 8. Individual treatment means and orthogonal contrast results for winter wheat grain yield. The values are corrected for dockage and to 14.5% seed moisture content. Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Treatment	2018-19	2019-20	2020-21	Average
	Grain Yield (kg/ha)			
Control (7 kg N/ha + residual)	2570	2171	2166	2302
	100% Side-Banded Urea			
60 kg N/ha	3430 a	3429 efg	2966 cd	3275 F
90 kg N/ha	3819 a	4114 bcde	3410 abcd	3781 CD
120 kg N/ha	3828 a	4336 abcd	3534 abcd	3899 CD
150 kg N/ha	4059 a	4788 ab	3848 a	4231 A
180 kg N/ha	3952 a	4767 ab	3703 ab	4141 A
fSB – linear	<0.001	<0.001	<0.001	<0.001
fSB – quad	<0.001	<0.001	<0.001	<0.001
	100% Spring Broadcast Urea			
60 kg N/ha	3441 a	2987 g	3076 bcd	3168 F
90 kg N/ha	3634 a	3678 defg	3404 abcd	3572 E
120 kg N/ha	3888 a	4083 bcde	3763 a	3912 BCD
150 kg N/ha	3926 a	4429 abc	3749 a	4035 ABC
180 kg N/ha	4075 a	4585 abc	4032 a	4230 A
sBC – linear	<0.001	<0.001	<0.001	<0.001
sBC – quad	<0.001	<0.001	<0.001	<0.001
	50:50 Split-application of Urea			
60 kg N/ha	3530 a	3305 fg	2927 d	3254 F
90 kg N/ha	3670 a	3892 cdef	3547 abcd	3703 DE
120 kg N/ha	3891 a	4238 bcd	3498 abcd	3876 BCD
150 kg N/ha	3949 a	4580 abc	3726 ab	4085 AB
180 kg N/ha	4088 a	4842 a	3662 abc	4197 A
Split – linear	<0.001	<0.001	<0.001	<0.001
Split – linear	<0.001	<0.001	<0.001	<0.001
S.E.M.		129.6		74.8

Table 9. Main effect means for average N timing/placement (TP) effects on winter wheat grain protein concentrations. Means within a group (Yr x TP; TP) followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Treatment	2018-19	2019-20	2020-21	Average
	---------- *Grain Protein (%)* ----------			
Control	10.4	9.9	10.6	10.3
Side-Banded	12.6 a	11.2 c	12.1 a	12.0 B
Spr. Broadcast	12.9 a	11.7 a	11.8 a	12.2 A
50:50 Split App.	12.8 a	11.4 b	11.9 a	12.0 B
S.E.M.		0.11		0.06

Table 10. Main effect means and orthogonal contrast results for average N rate (NR) effects on winter wheat grain protein concentrations. Means within a group (Yr x NR; NR) followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Treatment	2018-19	2019-20	2020-21	Average
	---------- *Grain Protein (%)* ----------			
Control	10.4	9.9	10.6	10.3
60 kg N/ha	11.0 d	9.8 c	10.9 d	10.6 E
90 kg N/ha	12.3 c	10.3 c	11.7 c	11.4 D
120 kg N/ha	13.2 b	11.8 b	12.2 b	12.4 C
150 kg N/ha	13.5 ab	12.2 b	12.4 ab	12.7 B
180 kg N/ha	13.8 a	13.0 a	12.6 a	13.1 A
S.E.M.		0.13		0.07
	---------- *p-value* ----------			
NR – linear	<0.001	<0.001	<0.001	<0.001
NR – quad	0.004	<0.001	0.089	0.693

Table 11. Individual treatment means and orthogonal contrast results for winter wheat grain protein. The values are corrected for dockage and to 14.5% seed moisture content. Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* ≤ 0.05).

Treatment	2018-19	2019-20	2020-21	Average
	------------ *Grain Protein (%)* ------------			
Control (7 kg N/ha + residual)	10.4	9.9	10.6	10.3
	------------ *100% Side-Banded Urea* ------------			
60 kg N/ha	11.2 d	9.7 f	11.4 bcd	10.8 F
90 kg N/ha	12.2 c	9.8 f	11.8 abc	11.3 E
120 kg N/ha	13.1 bc	11.8 cd	12.5 a	12.4 CD
150 kg N/ha	13.2 abc	12.0 bc	12.5 a	12.6 BCD
180 kg N/ha	13.4 ab	12.8 ab	12.5 a	12.9 ABC
fSB – linear	<0.001	<0.001	<0.001	<0.001
fSB – quad	0.002	<0.001	0.004	0.434
	------------ *100% Spring Broadcast Urea* ------------			
60 kg N/ha	11.0 d	10.2 ef	10.6 d	10.6 F
90 kg N/ha	12.3 c	10.8 de	11.6 bc	11.6 E
120 kg N/ha	13.3 ab	11.9 bc	12.0 abc	12.4 D
150 kg N/ha	13.9 ab	12.5 abc	12.4 abc	12.9 AB
180 kg N/ha	14.2 a	13.1 a	12.6 a	13.3 A
sBC – linear	<0.001	<0.001	<0.001	<0.001
sBC – quad	0.189	0.051	0.964	0.730
	------------ *50:50 Split-application of Urea* ------------			
60 kg N/ha	10.9 d	9.6 f	10.8 cd	10.4 F
90 kg N/ha	12.4 c	10.2 ef	11.7 bc	11.4 E
120 kg N/ha	13.2 abc	11.7 cd	12.2 abc	12.4 D
150 kg N/ha	13.5 ab	12.2 abc	12.4 ab	12.7 BCD
180 kg N/ha	13.9 ab	13.1 a	12.6 a	13.2 A
Split – linear	<0.001	<0.001	<0.001	<0.001
Split – linear	0.055	<0.001	0.406	0.191
S.E.M.		0.18		0.11

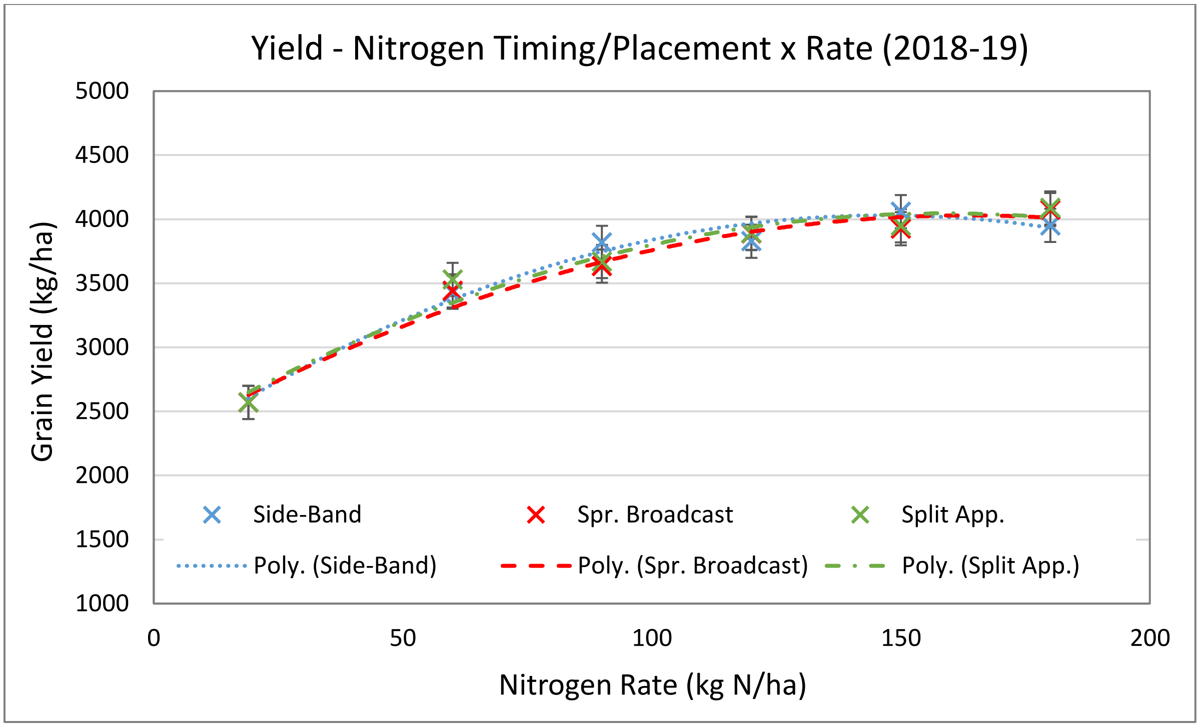

Figure 7. Winter wheat yield response to varying rates of side-banded, spring broadcast, or split-applied nitrogen (N) at Indian Head in 2018-19. The N rates include fertilizer plus soil N which was 12 kg NO_3-N/ha in 2018-19. Error bars are the standard error of the treatment means.

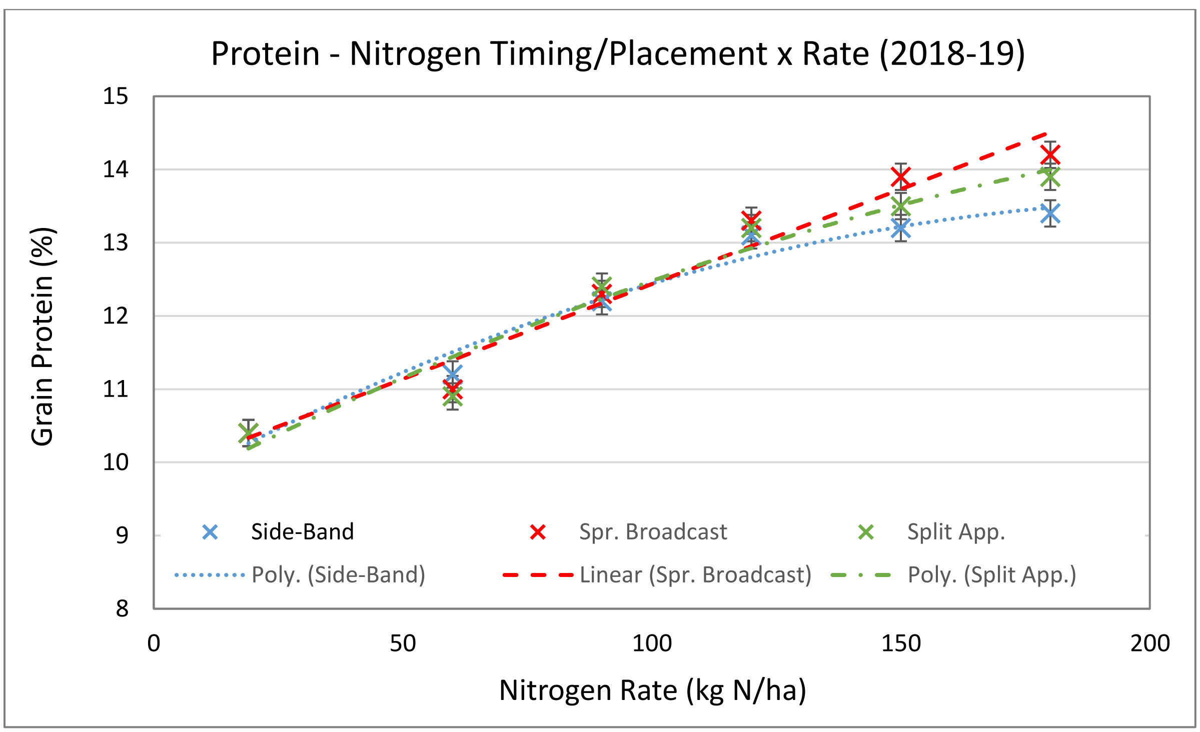

Figure 8. Winter wheat protein response to varying rates of side-banded, spring broadcast, or split-applied nitrogen (N) at Indian Head in 2018-19. The N rates include fertilizer plus soil N which was 12 kg NO_3-N/ha in 2018-19. Error bars are the standard error of the treatment means.

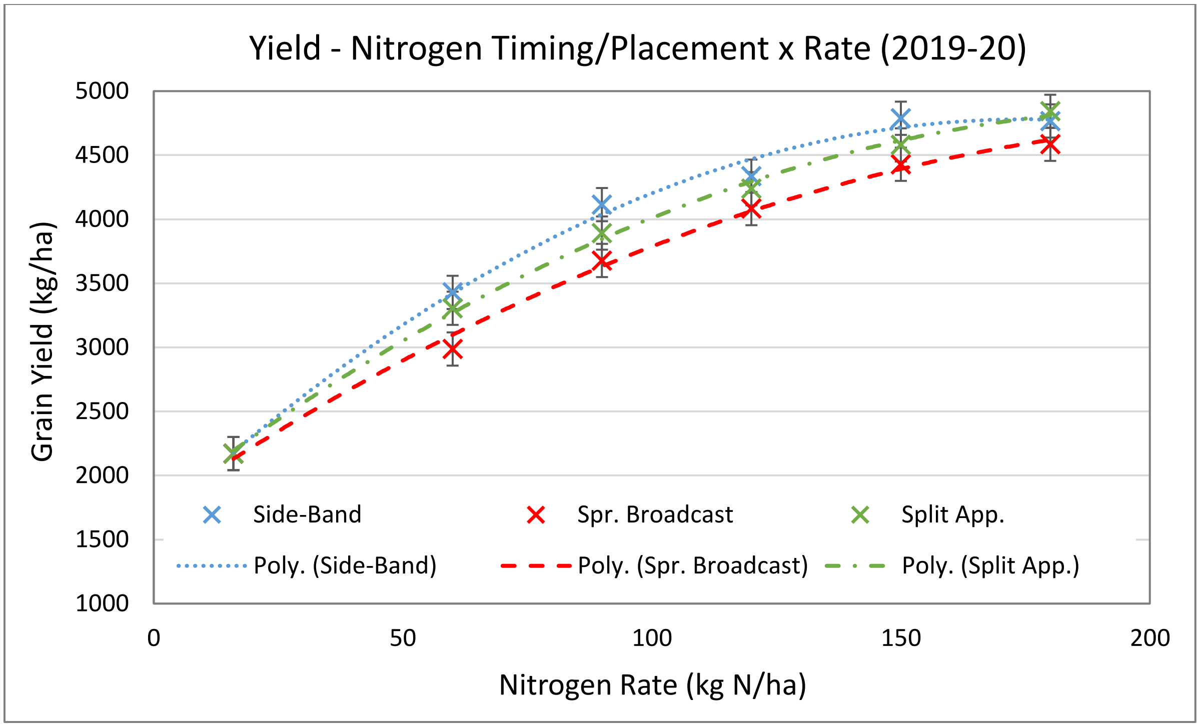

Figure 9. Winter wheat yield response to varying rates of side-banded, spring broadcast, or split-applied nitrogen (N) at Indian Head in 2019-20. The N rates include fertilizer plus soil N which was 9 kg NO_3-N/ha in 2019-20. Error bars are the standard error of the treatment means.

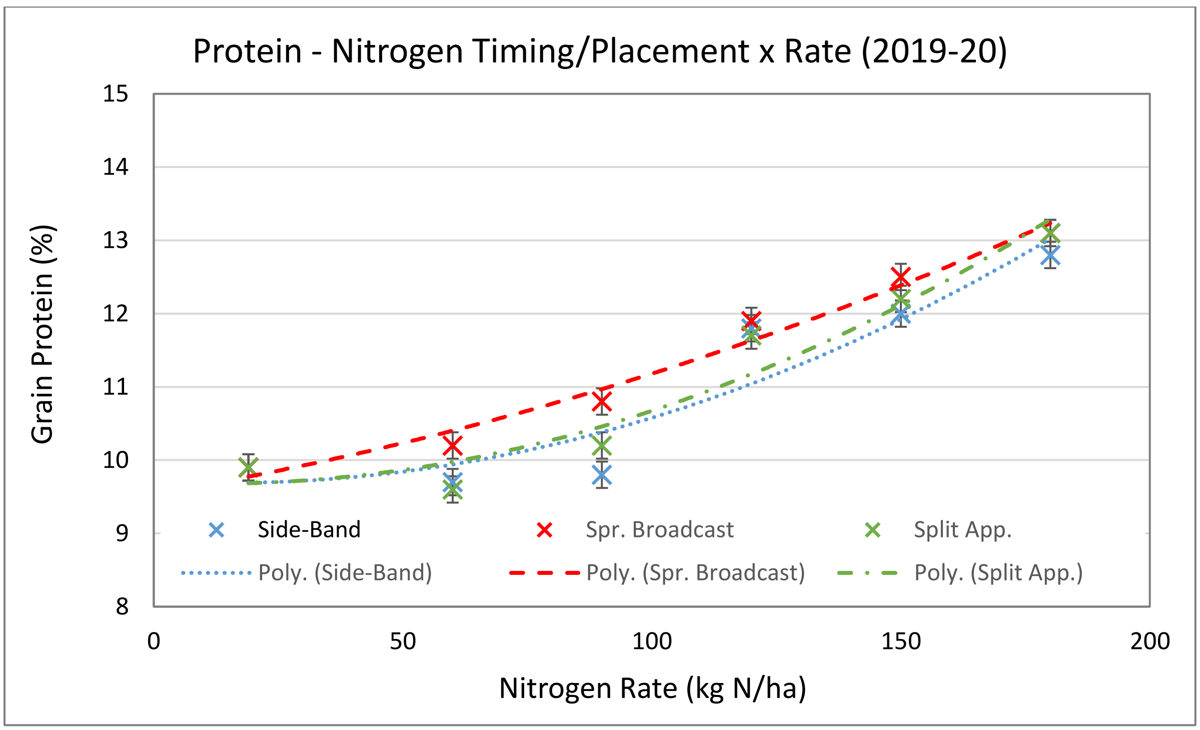

Figure 10. Winter wheat protein response to varying rates of side-banded, spring broadcast, or split-applied nitrogen (N) at Indian Head in 2019-20. The N rates include fertilizer plus soil N which was 9 kg NO_3-N/ha in 2019-20. Error bars are the standard error of the treatment means.

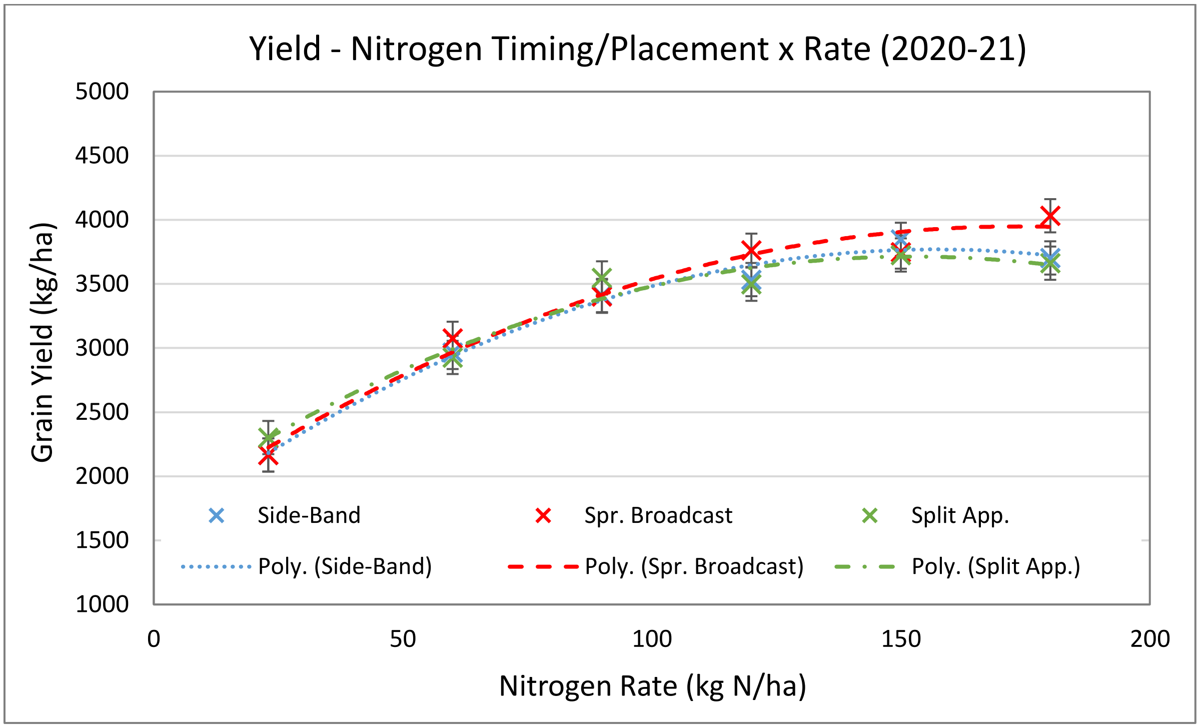

Figure 11. Winter wheat yield response to varying rates of side-banded, spring broadcast, or split-applied nitrogen (N) at Indian Head in 2020-21. The N rates include fertilizer plus soil N which was 16 kg NO_3-N/ha in 2020-21. Error bars are the standard error of the treatment means.

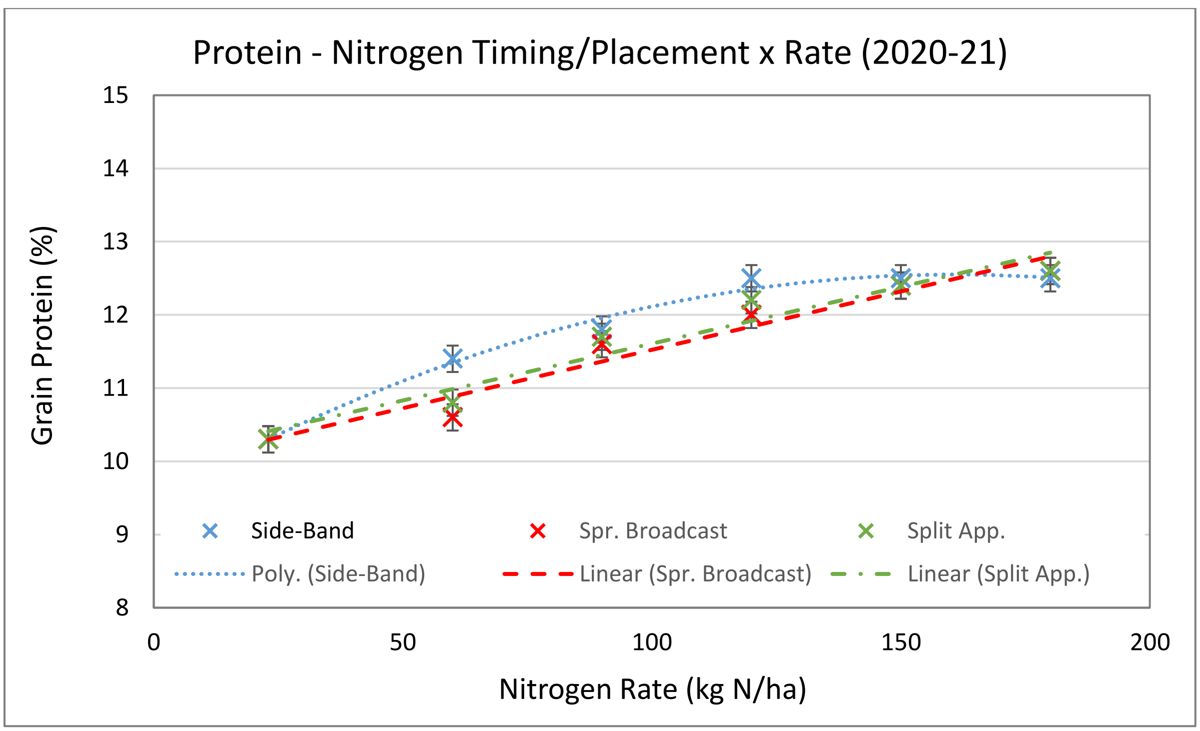

Figure 12. Winter wheat protein response to varying rates of side-banded, spring broadcast, or split-applied nitrogen (N) at Indian Head in 2020-21. The N rates include fertilizer plus soil N which was 16 kg NO_3-N/ha in 2020-21. Error bars are the standard error of the treatment means.

Table 12. Overall F-tests and treatment means comparing winter wheat yield and protein response to contrasting nitrogen (N) treatments at Indian Head, 2020-21.

Source / Treatment	Grain Yield	Grain Protein
	------------ kg/ha ------------	--------------- % ---------------
Control [Z]	2166 B	10.60 B
Untreated Urea [Y]	3763 A	11.97 A
NBPT Treated Urea [Y]	3726 A	12.04 A
S.E.M.	99.6	0.120
	------------------------------ p-value	------------------------------
Overall F-test	< 0.001	< 0.001
Untreated vs NBPT	0.581	0.565

[Z] 23 kg N/ha from residual soil NO_3-N and MAP (11-52-0)
[Z] 120 kg N/ha with 23 kg N/ha from residual soil NO_3-N and MAP and the rest as an early-spring broadcast

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Abstract

14. Abstract/Summary

With funding from the Saskatchewan Ministry of Agriculture's ADOPT program and Fertilizer Canada, a nitrogen (N) management demonstration with winter wheat was initiated in 2018-19 and repeated for each of the following two growing seasons. The field trials were located near Indian Head in the thin-Black soil zone of southeast Saskatchewan. The treatments were a factorial combination of three N timing/placement strategies (100% sideband; 100% early-spring broadcast; 50:50 split-application) and five N rates (60, 90, 120, 150, and 180 kg N/ha) plus a control where no supplemental N was applied. The N rates included residual soil NO_3-N and, unless otherwise indicated, the N source was untreated urea. The response variables of interest were grain yield and grain protein. Winter wheat yields were optimized with 120-150 kg N/ha (soil plus fertilizer) with quadratic responses detected in all three years and the strongest overall response observed in 2019-20, the latter which was also the season where the highest yields were achieved. Grain protein also responded to N rate but continued increasing at higher N rates compared to yield and, in some cases, the response was linear. Regarding timing/placement effects, environmental conditions were not particularly conducive to leaching or denitrification losses of fall-applied N and timely spring precipitation limited the potential volatile losses while increasing availability of the early-spring broadcast N. As such, all of the N timing/placement options performed reasonably well. In two of three seasons and when averaged over the three-year period, there were no significant differences between timing/placement methods for either yield or protein when averaged across rates. The exception was in 2019-20 where yields were highest with side-banded N but protein was higher with spring broadcast N. Results with the split-applications were intermediate when differences occurred but generally were more similar to the fall side-band applications. This suggests that actual losses were not necessarily higher with the spring applied N; however, the availability shifted later into the growing season at the expense of yield but in favour of protein synthesis. While all three timing/placement strategies performed reasonably well under the conditions encountered, split-applications provide added flexibility and can buffer against both fall/early-spring N losses and early-spring N deficiencies.
