2021 Annual Report

for the

Saskatchewan Ministry of Agriculture's

Agricultural Demonstration of Practices & Technologies (ADOPT) Program

and Fertilizer Canada

Project Title: Crop Response to Shallow versus Deep Banded Nitrogen Relative to Benchmark Practices

(Project #20200435)

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Project Identification

1. **Project Title:** Crop response to shallow- versus deep-banded nitrogen fertilizer formulations relative to other benchmark practices

2. **Project Number:** 20200435

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:**

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Objectives and Rationale

7. **Project Objectives:**
Developing Best Management Practices (BMPs) for applications of nutrients such as nitrogen (N) 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 of nutrient sources. In addition to agronomic performance and fertilizer use-efficiency, farmers must also consider logistic and economic factors when deciding how to best manage N. The objectives of this project were:

   1) To demonstrate the potential benefits, under field conditions, of banding urea at depths of at least 5 cm relative to the shallower banding depths commonly achieved when side-banding is combined with shallow seeding, and other benchmark practices.

   2) To demonstrate the potential benefits, under field conditions, of utilizing a commercially available volatilization/nitrification inhibitor to mitigate the risk of N losses for contrasting fertilizer placement and timing options.

8. **Project Rationale:**
Nearly forty years ago, John Harapiak and his colleagues initiated a major shift in how N fertilizer was managed in western Canada. They achieved this by proving and communicating the benefits of applying fertilizer beneath the soil surface in concentrated bands prior to seeding. Work from this era also found that banding depths of 7.5-10 cm (3-4") were ideal when both machinery capabilities and agronomic performance were considered. At this time, fertilization and seeding were primarily completed in two separate operations; however, seeding equipment rapidly evolved and single pass seeding/fertilization systems soon became the preferred and most recommended option. Banding the N fertilizer beneath the soil surface at precisely same time as the crop is seeded was, and still is, seen by many as near perfect fit with spring seeded crops in our short, frequently dry Western Canadian growing seasons.

Since this early work was completed, however, crop rotations have changed, farm sizes and fertilizer rates have increased, equipment capabilities/configurations have been diversified, and there is growing concern that our side- or mid-row banded urea may not always be as safe or efficient as previously assumed. Furthermore, with large farms and narrow seeding windows, there has been some movement back to two-pass seeding/fertilization systems, in many cases utilizing surface broadcast applications, as a means of reducing logistic pressure during seeding. Enhanced efficiency fertilizer products (such as Agrotain® or SUPERU®) may be viable options for offsetting the increased potential for N losses due to sub-optimal placement (i.e., shallow-banding or surface broadcast) or timing (i.e. fall) options. This project was initiated to demonstrate the relative crop responses to N fertilizer under contrasting management strategies along with the potential benefits of using N treated with both volatilization and nitrification inhibitors. The comparison between shallow- and deep-banding will provide insights that are applicable to both two-pass and single-pass seeding/fertilization systems. The intent of applying the fertilizer in the fall for these treatments was to ensure sufficient time for losses to occur between fertilization and peak crop uptake.

Although the results from this project are applicable to all crops that require N fertilizer, CWRS wheat was considered an ideal test crop in that it is responsive to high rates of N, widely adapted, and economically important in Saskatchewan and western Canada as a whole. Importantly, high protein is required for achieving top grades of CWRS wheat and grain protein is also an excellent indicator of overall N availability, often more responsive to N than yield.

Methodology and Results

9. Methodology:

A field trial with CWRS wheat was initiated with the first N treatments applied in the fall of 2019 followed by subsequent treatment applications and seeding in the early spring of 2020. The project was repeated in 2020-21. The treatments were a combination of six N fertilizer rate/placement/timing strategies and two formulations, plus a control where no supplemental N was applied. The timing/placement options were side banding, fall surface-broadcast, spring surface-broadcast, fall deep-banding, and fall shallow-banding. The two formulations were untreated urea and an enhanced efficiency option, SUPERU®. Specifically, SUPERU® is urea treated with 0.85% dicyandiamide (DCD; nitrification inhibitor) and 0.06% N-(n-butyl) thiophosphoric triamide (NBPT; urease inhibitor). Nitrification inhibitors slow the conversion from NH_4^+ to NO_3^-, reducing the potential for leaching or denitrification losses to occur. Urease inhibitors slow the hydrolyses of urea, reducing the risk of NH_3 volatilization losses, particularly if the fertilizer is either stranded on the soil surface or concentrated in shallow bands. For the control treatment, the only N fertilizer applied was 7 kg N/ha from seed-placed monoammonium phosphate (11-52-0). The N fertilizer rates in all but the control were adjusted for residual soil NO_3-N and the 1x rate of 110 kg N/ha (residual plus fertilizer) was intended to be below what was expected to be required for maximum yield and protein. A high N side-band treatment (1.5x – 165 kg total N/ha) was also included to confirm that the 1x rate was not so high that it could mask subtle differences amongst the N timing, placement, and form options. The treatments were arranged in a four replicate RCBD and are described in greater detail in Table 1.

Table 1. Nitrogen management treatments evaluated for CWRS wheat at Indian Head in 2020 and 2021.

#	N Form	Treatment Name	Band Depth	Total N Rate [Z]
1	n/a	control	n/a	7 kg N/ha [Y] + residual
2	Untreated urea	high N side-band	≈3.5 cm (1.5”)	1.5x – 165 kg N/ha
3	Untreated urea	side-band	≈3.5 cm (1.5”)	1.0x – 110 kg N/ha
4	Untreated urea	fall surface broadcast	0 cm (0”)	1.0x – 110 kg N/ha
5	Untreated urea	spring surface broadcast	0 cm (0”)	1.0x – 110 kg N/ha
6	Untreated urea	fall deep-band	≈5.6 cm (2.3”)	1.0x – 110 kg N/ha
7	Untreated urea	fall shallow-band	≈2.5 cm (1”)	1.0x – 110 kg N/ha
8	SUPERU®	high N side-band	≈3.5 cm (1.5”)	1.5x – 165 kg N/ha
9	SUPERU®	side-band	≈3.5 cm (1.5”)	1.0x – 110 kg N/ha
10	SUPERU®	fall surface broadcast	0 cm (0”)	1.0x – 110 kg N/ha
11	SUPERU®	spring surface broadcast	0 cm (0”)	1.0x – 110 kg N/ha
12	SUPERU®	fall deep-band	≈5.6 cm (2.3”)	1.0x – 110 kg N/ha
13	SUPERU®	fall shallow-band	≈2.5 cm (1”)	1.0x – 110 kg N/ha

[Z] Includes residual NO_3-N (0-60 cm) estimated from fall composite soil samples
[Y] Provided by seed-placed 11-52-0 for all treatments

The fall banding treatments and seeding/side-banding were completed using an eight-opener SeedMaster plot drill which positions the side-banded fertilizer approximately 1. 5” (3.7 cm) beside and 0.75” (1.8 cm) below the seed-row. With a target seed depth of 0.75” (1.8 cm), the side-banded fertilizer depth was approximately 1.5” (3.8 cm). Depth of the fall banded treatments were varied as per protocol by either setting the drill to its shallowest marked setting (≈2.5 cm side-band depth) or the deepest possible setting (≈5.6 cm side-band depth). Broadcast N treatments were applied using handheld spreaders and pre-weighed quantities of fertilizer. The fall fertilizer treatments were applied on October 7 (2019) and October 8 (2020), while the spring broadcast treatments were applied on May 10 (2020) and May 8 (2021). Seeding/side-banding was completed on May 11 in 2020 and May 10 in 2021. Nutrients other than N were intended to be non-limiting. The variety was CDC Alida VB and the target seeding rate was 325 seeds/m^2 in 2020 and 375 seeds/m^2 in 2021. Weeds were controlled using registered pre-harvest and in-crop herbicides, fungicides were applied preventatively at approximately 50% anthesis, and insecticides were not required in either year. The centre five rows of each plot were straight combined on August 26 (2020) and August 30 (2021). Selected agronomic details and dates of field operations are provided in Table 4 of the Appendices.

Residual soil nutrients and basic characteristics were determined from composite soil samples collected in the fall and submitted to AgVise Laboratories (Northwood, ND, USA). Results from these analyses were also used to adjust the N fertilizer rates. 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 from two sub-samples per plot using a FOSS NIR analyzer.

Response data from both years were combined and analyzed using the generalized linear mixed model (GLIMMIX) procedure in SAS® Studio. Heterogeneous estimates of variance components were permitted between years and, for both yield and protein, improved the overall model fit. The effects of year (Yr), treatment (Trt), and the Yr x Trt interaction were considered fixed and replicate effects (within year) were treated as random. Predetermined contrasts were used to compare the

1x and 1.5x rates, two fertilizer forms, alternative timing/placement options to side-banding, fall broadcast to spring broadcast, and shallow-banding to deep-banding. All treatment effects and differences between means were considered significant at $P \leq 0.05$ and the conservative Tukey-Kramer test was used to separate treatment means.

10. Results:

Growing season weather and residual soil nutrients

For both years, mean monthly temperatures and total precipitation amounts for May-August are presented alongside the long-term (1981-2010) averages in Table 2. Information from the previous fall months is also provided to coincide with the fall N applications. The fall of 2019 was wet with 121 mm of precipitation in September while October, when the fall N fertilizer treatments were applied, was cooler than average. The cool temperatures would have slowed urea hydrolysis and nitrification; thus, reducing potential for fall/early spring N losses to some extent. While the rain in September helped to replenish soil moisture reserves, less than 6 mm of total precipitation fell over the two-weeks following the fall N applications in 2019 and just over 10 mm was received for the entire month of October. Similarly, the period following the spring N applications was also dry with less than 6 mm of precipitation over the two-weeks following the N applications and only 6 mm for the entire month of May (2020). The limited precipitation following the fall and early spring N applications was not likely sufficient to completely move the surface applied N into the rooting zone and fully mitigate volatilization losses. For the second year of the project (2020-21), the fall was extremely dry with low soil moisture reserves at the time of the fall N applications and essentially no rain to move the applied N into the rooting zone where it would be safe from volatilization and available to the crop. Conditions early in the following spring and at the time of the spring broadcast applications were also extremely dry; however, 80 mm of precipitation fell within 16 days of the applications and conditions leading up to this were cool and not generally conducive to high losses of N. With well-drained sites and essentially no periods of excess moisture and/or saturated soils, the risks of denitrification and/or leaching were considered low over the entire duration of the project. Growing season conditions were, in general, dry both years and yields were considered slightly below-average to approximately average. While the 4-month (May-August) precipitation total for 2021 was 121% of the long-term average, initial soil moisture reserves were extremely low, temperatures were above-average, and 30% of the reported growing season precipitation fell within the last two weeks of August, too late to be of much benefit. In contrast, growing season precipitation was less than 50% of average the previous season (2020); however, temperatures were considerably cooler and the season started with a full profile of soil moisture.

Table 2. Mean monthly temperatures and precipitation amounts along with long-term (1981-2010) averages for the 2020 and 2021 growing seasons and preceding fall months at Indian Head, SK.

Year	Prev. Sep	Prev. Oct	May	June	July	August	May-Aug
	---------- Mean Temperature (°C) ----------						
2020	11.9	1.0	10.7	15.6	18.4	17.9	15.7 (101%)
2021	11.5	1.4	9.0	17.7	20.3	17.1	16.0 (103%)
LT	11.5	4.0	10.8	15.8	18.2	17.4	15.6
	---------- Total Precipitation (mm) ----------						
2020	120.8	10.4	27.3	23.5	37.7	24.9	113 (46%)
2021	15.0	3.8	81.6	62.9	51.2	99.4	295 (121%)
LT	35.3	24.9	51.8	77.4	63.8	51.2	244

The field trials were located east of Indian Head (R.M. #156), within less than 1 km of each other and on land with similar management history and overall soil characteristics. In both years, the trials were established on canola stubble, soil pH for the upper 15 cm was 7.9-8.0, and soil organic matter was 4.6-4.8% (Table 3). Residual phosphorus was consistently low and supplemented with seed-placed mono-ammonium phosphate while potassium and sulfur were unlikely to be limiting. Importantly, residual NO_3-N was quite low in both years, estimated at only 9 kg N/ha (0-60 cm soil depth) in 2020 and 16 kg N/ha in 2021. This was ideal for demonstrating the various N fertilization strategies as it ensured that much of the N available to the test crops would be provided by the applied N fertilizer as opposed to residual N and mineralization of organic matter.

Table 3. Soil test results for 4R nitrogen management demonstrations at Indian Head in 2020 and 2021.

Year	Depth	pH	O.M. (%)	NO_3-N (kg/ha)	Olsen-P (ppm)	K (ppm)	S (kg/ha)
2020	0-15	7.9	4.6	6	2	516	11
	15-60	8.2	–	3	–	–	27
	0-60	–	–	9	–	–	38
2021	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 Treatments

Results from the tests of fixed effects and model fit statistics are presented in Table 5 of the Appendices. Both yield and protein were affected by year (P < 0.001-0.039) and N treatment (P < 0.001) with significant Yr x Trt interactions detected (P < 0.001-0.019). The year effects (data not shown) was such that yields were higher on average in 2020 (4325 kg/ha) than in 2021 (3591 kg/ha). The opposite occurred for protein whereby the values were lower, on average, in 2020 (12.4%) than in 2021 (13.0%). Detailed results tables for treatment means and results of the Tukey-Kramer test are provided in the Appendices but are also provided in the form of simplified figures through the main body of the report. Because of the significant Yr x Trt interactions, results from individual years are generally of greater interest and will be discussed in greater detail than the averaged results.

In 2020 (Fig. 1; Table 6), all of the individual fertilized treatments (3908-5142 kg/ha) yielded higher than the control (2521 kg/ha). The trends for protein were similar (10.4% versus 11.1-14.7%); however, not all individual values significantly differed from the control according to the multiple comparisons test (Fig. 2; Table 10). The contrast comparing the 1.5x N rate to the 1x rate with side-banding in 2020 was also significant ($P < 0.001$) for both yield (5109 kg/ha versus 4749 kg/ha; Table 7) and protein (14.6% versus 12.9%; Table 11). This indicated that the 1x rate was appropriate for detecting differences between the various N management strategies. When untreated urea and SUPERU® were compared across all rates and timing/placement options, no effects on either yield (4454-4495 kg/ha; $P = 0.215$) or protein (12.5-12.6%; $P = 0.326$) were detected in the first year of the demonstration. Inspection of the individual treatment means (Fig. 1-2; Tables 6 and 10) shows that fertilizer effects varied across timing/placement options but the trends and general performance were similar for both N formulations.

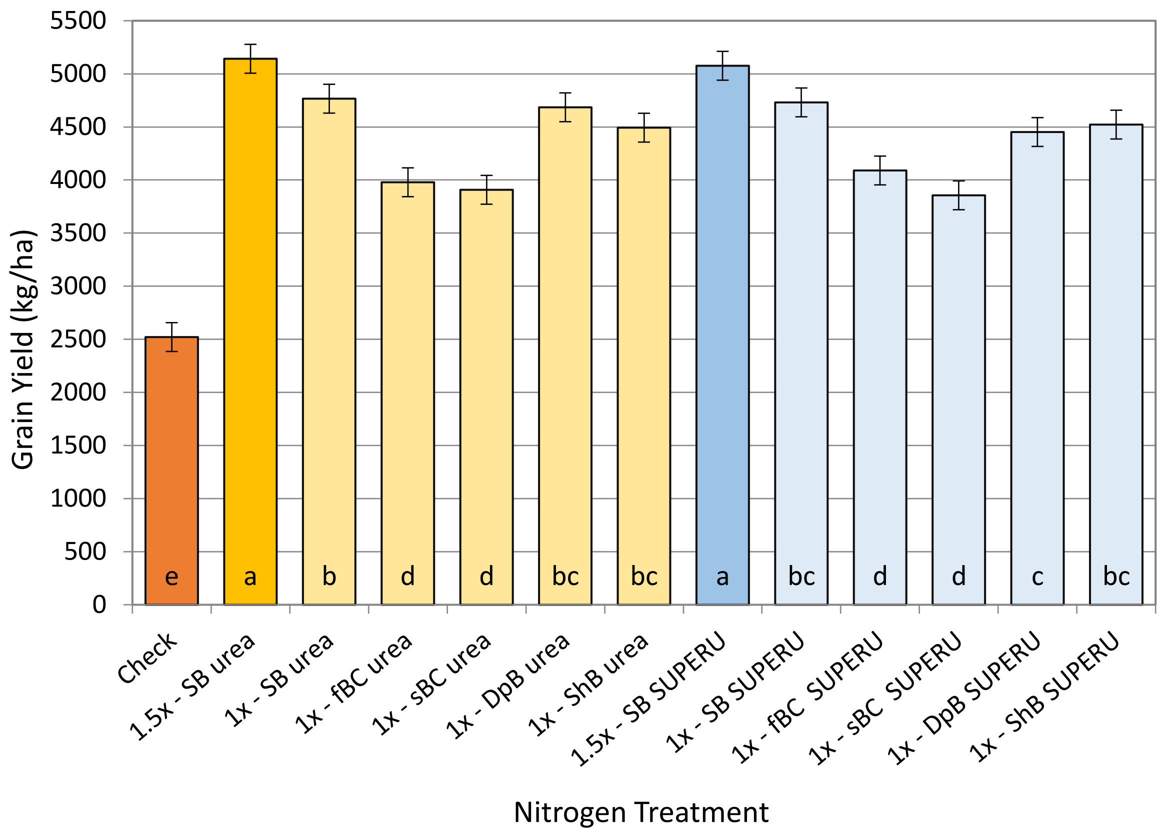

Figure 1. Individual nitrogen treatment means for spring wheat yield at Indian Head in 2020. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.

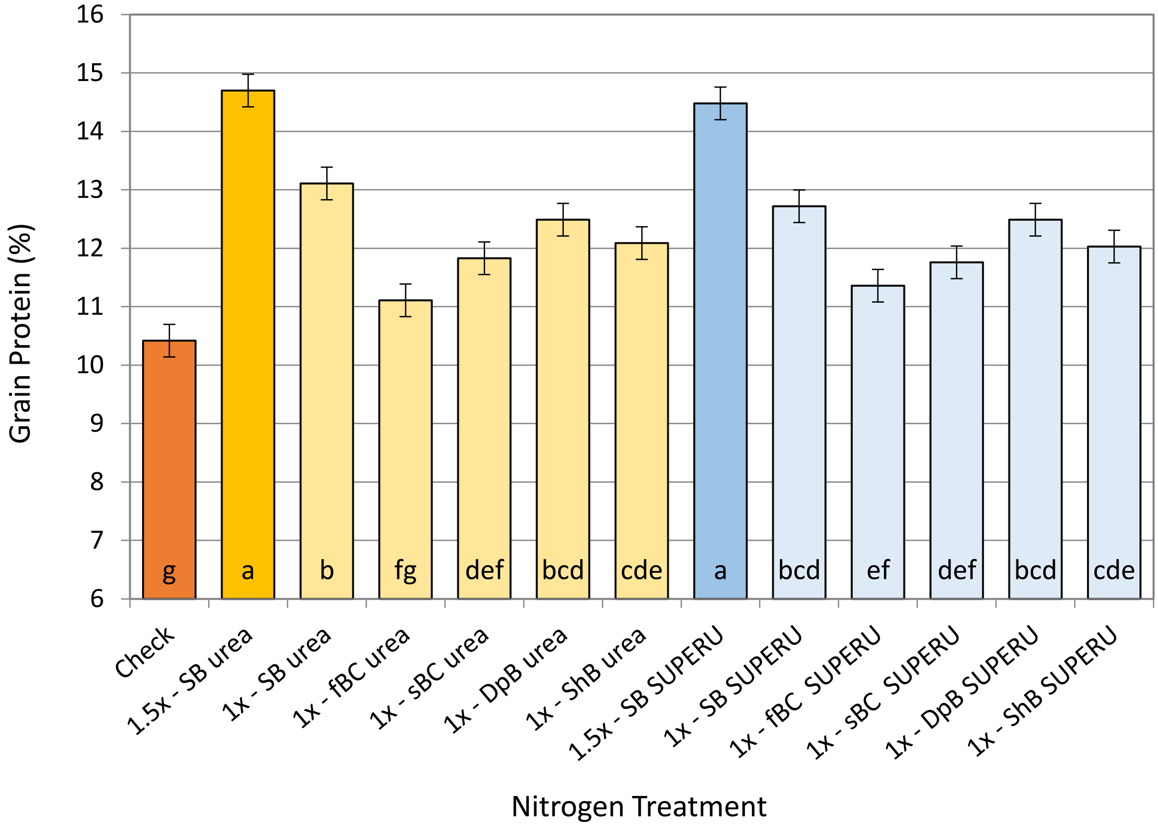

Figure 2. Individual nitrogen treatment means for spring wheat protein at Indian Head in 2020. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.

To better focus on the relative performance of the various timing/placement options compared to side-banding, contrast results for the 2020 season are presented in Fig. 3 below and also in Tables 7 and 11. The trends were mostly similar for both variables whereby none of the alternative options performed as well as side-banding; however, there was wide-variation amongst the two-pass seeding/fertilization systems. First, both of the in-soil placement options (fall shallow-band and fall deep-band) performed better than the broadcast options with regard to their effects on yield and protein. Regardless of timing (i.e., fall versus spring), broadcasting the N on the soil surface with no incorporation resulted in substantial yield and protein reductions compared to the in-soil placement options, especially, side-banding. When comparing fall broadcast to spring broadcast, the effects on yield and protein differed in that fall-broadcasting resulted in slightly higher yields (4035 kg/ha versus 3882 kg/ha; $P = 0.009$) but lower protein (11.2% versus 11.8%; $P < 0.001$). Again, while there was abundant soil moisture in the fall of 2019, very little precipitation was received after the N applications to move the applied N into the rooting zone. In terms of relative yield loss in 2020 (compared to side-banding), the best performance was observed with fall deep-banding (181 kg/ha or 3.8% losses), followed by fall shallow-banding (242 kg/ha or 5.1% losses), fall broadcast (714 kg/ha or 15% losses), and spring broadcast (867 kg/ha or 18% losses). For protein loss relative to side-banding, the best performance was with fall deep-banding (0.4 g/100 g or 3.3% losses), followed by fall shallow-banding (0.9 g/100 g or 6.6% losses), spring broadcast (1.1 g/100 g or 8.7% losses), and fall broadcast (1.7 g/100 g or 12.9% losses). When comparing deep-banding specifically to shallow-banding (across N formulations), yields were similar 4507-4568 kg/ha; $P = 0.286$) but protein was higher with deep-banding (12.5% versus 12.1%; $P = 0.003$) indicating either slightly lower losses or enhanced availability with the deeper placement.

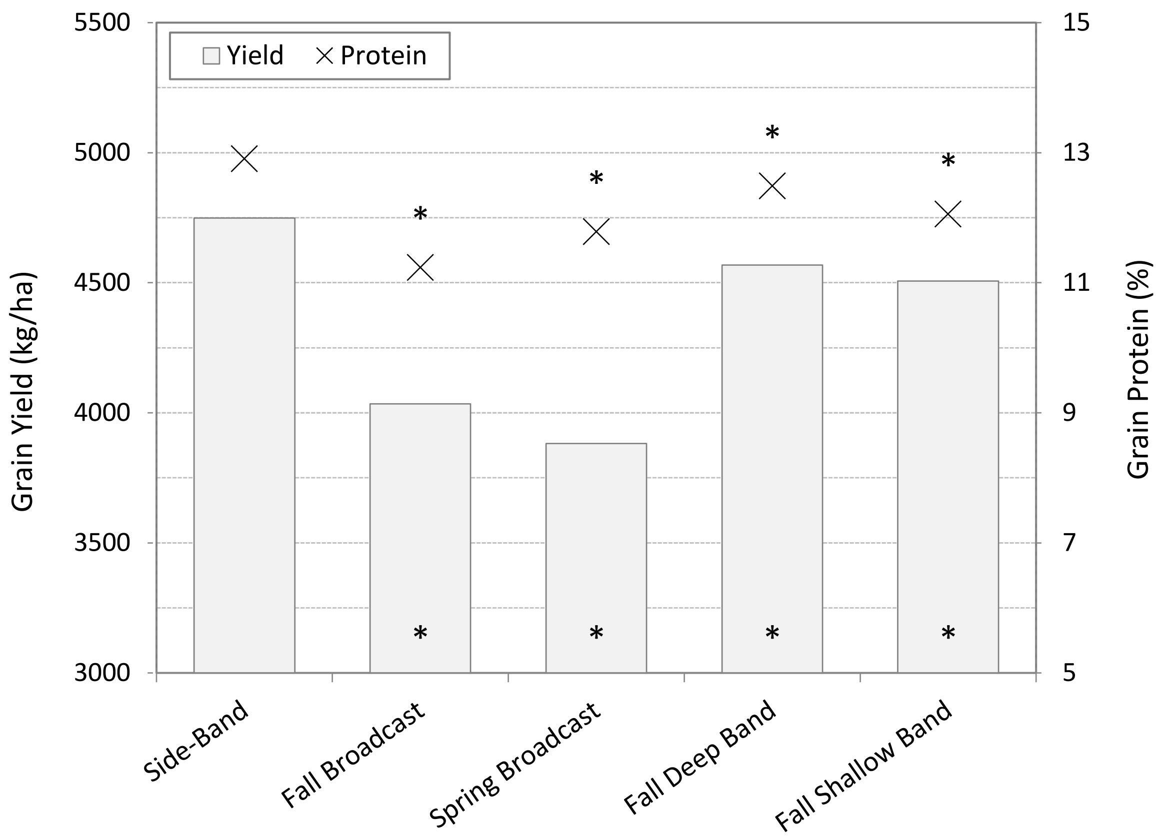

Figure 3. Contrasts comparing spring wheat yields and protein with side-banded nitrogen (N) fertilizer to alternative timing and placement options at Indian Head in 2020. All treatments received the 1x rate of 110 kg N/ha (soil + fertilizer) and values are the averages for untreated urea and SUPERU®. An asterisk (*) indicates that the value significantly differed from side-banding while 'ns' indicates that it did not (*P* ≤ 0.05).

As expected and similar to the previous season, all of the individual fertilized treatments (3257-4083 kg/ha) yielded higher than the control (1962 kg/ha) in 2021 (Fig. 4; Table 6). The same was true for protein (10.7% versus 11.5-15.0%) (Fig. 5; Table 10). Again, significant differences ($P = 0.001$) between N fertilizer side-banded at the 1.5x N rate and the 1x rate for both yield (Table 8) and protein (Table 12) confirmed that the 1x rate was appropriate for detecting differences associated with N form, timing, and placement options. The mean yield at the higher N rate was 4031 kg/ha compared to 3834 kg/ha at the 1x rate while, for protein, the values were 14.6% and 12.9%, respectively. In contrast to the previous season, there was a slight but significant advantage to SUPERU® over untreated urea detected for both yield ($P < 0.001$; Table 8) and protein ($P = 0.051$; Table 12) when averaged across both rates and timing/placement options. The observed relative advantages to SUPERU® in 2021 were 3.2% (3786 kg/ha versus 3669 kg/ha) for yield and 1.5% for protein (13.3 g/100g versus 13.1 g/100 g). Notably, and as expected, the greatest advantage to SUPERU® appeared to occur with the fall broadcast applications (Fig. 4 and 5; Tables 6 and 10); however, the conservative Tukey-Kramer multiple comparisons test did not find the differences between these individual treatment means to be significant at $P \leq 0.05$). Aside from the aforementioned differences in response with fall broadcast N, inspection of the individual treatment means showed mostly similar trends for both N formulations despite substantial variation across timing/placement options but (Fig. 4-5; Tables 6 and 10).

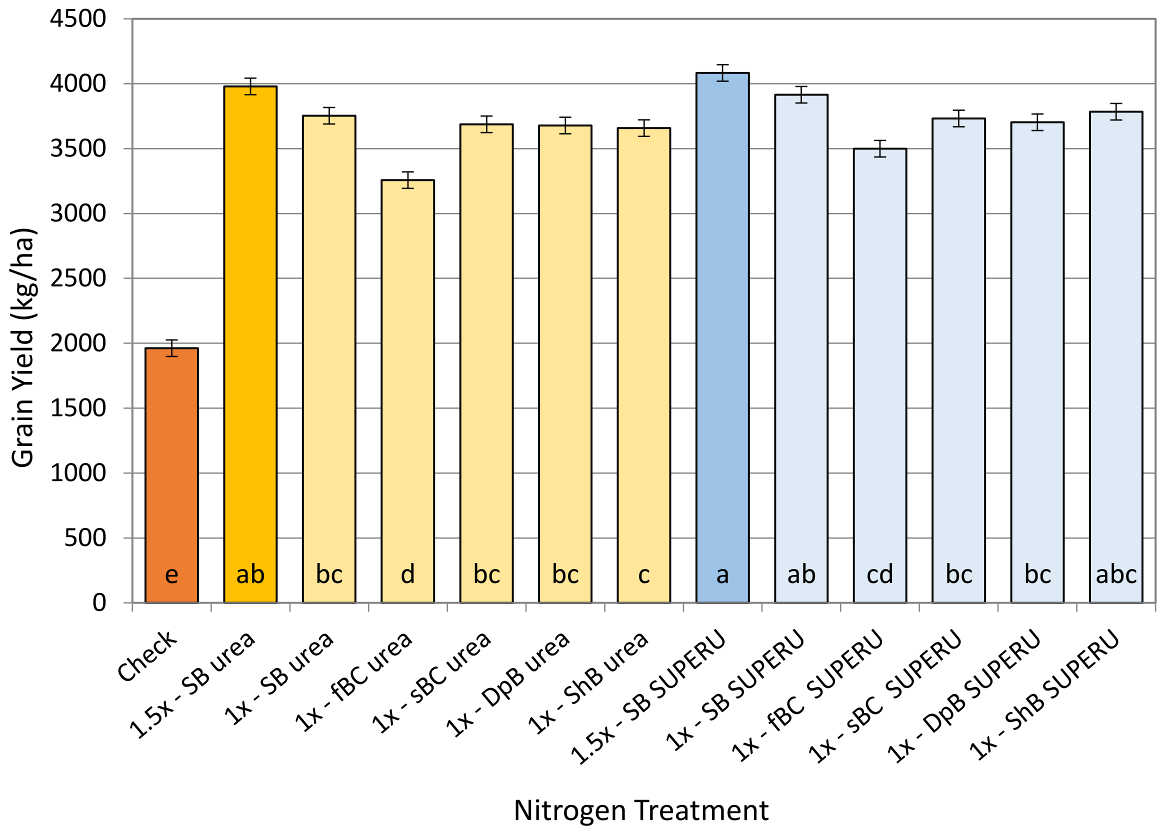

Figure 4. Individual nitrogen treatment means for spring wheat yield at Indian Head in 2021. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.

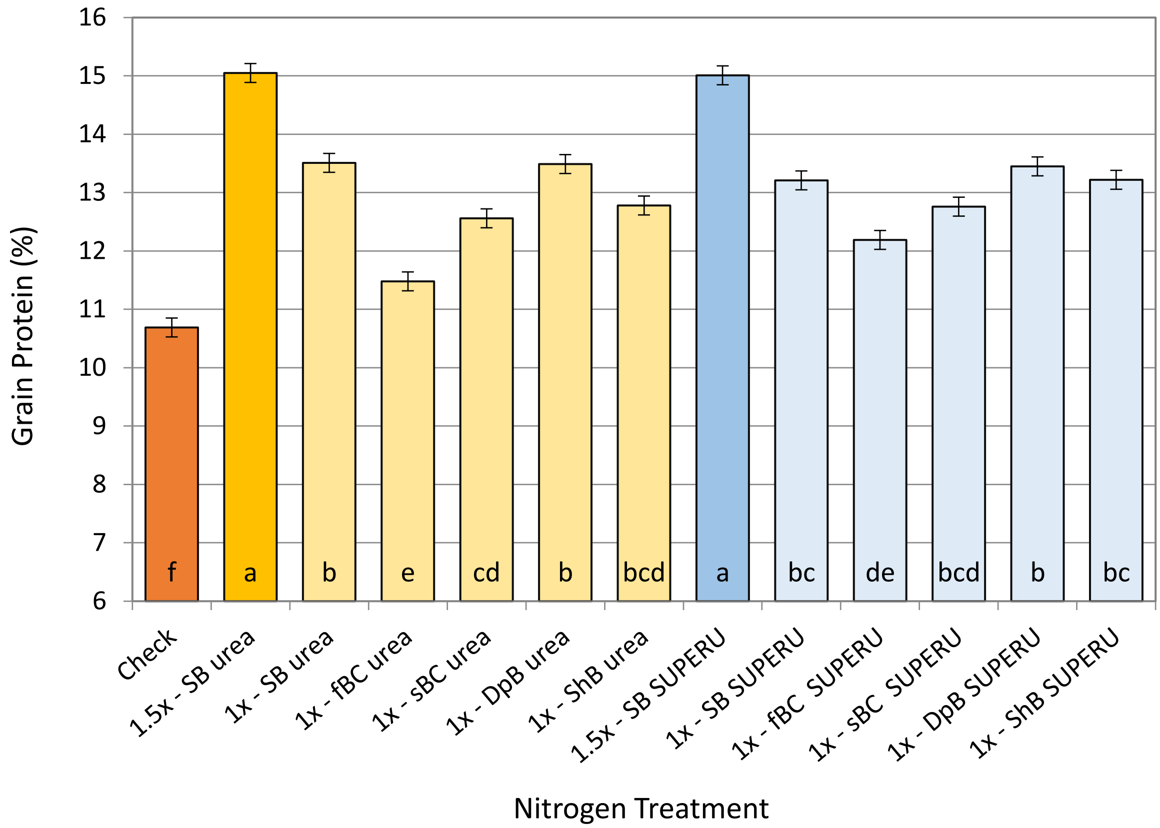

Figure 5. Individual nitrogen treatment means for spring wheat protein at Indian Head in 2021. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.

Results from the various contrast comparisons in 2021 are presented in Fig. 6 below and also in Tables 8 and 12 for yield and protein, respectively. Aside from the fact that side-banding performed best overall, the efficacy of the various two-pass seeding/fertilization systems differed relative to the previous year. For yield, none of the options performed as well as side-banding when averaged across N forms ($P < 0.001$-0.050). Fall banding (regardless of depth) was the best option relative to side-banding but still resulted in a yield loss of 113-144 kg/ha (3-4%; $P = 0.014$-0.050). Spring broadcasting resulted in a yield loss of 125 kg/ha (3%; $P = 0.031$) relative to side-banding which was similar to what was achieved with fall in-soil banding. Fall broadcasting was the poorest option, resulting in a 456 kg/ha (12%) yield loss relative to side-banding and, again, even higher losses when untreated urea (as opposed to SUPERU®) was applied in this manner. For protein, side-banding was advantageous over all timing/placement options ($P < 0.001$), except for fall deep-banding ($P = 0.422$). Shallow-banding resulted in 0.4 g/100 g less protein than side-banding, a relative reduction of 2.7% ($P = 0.014$). The reduction with spring broadcast N was 0.7 g/100 g (5.2%; $P < 0.001$) relative to side-banding and, with fall broadcast N, protein was reduced by 1.5 g/100 g (11.5%; $P < 0.001$). Looking more closely at the surface broadcast treatments, there was a substantial advantage to the spring applications compared to fall applications for both yield and protein. More specifically, yields were 331 kg/ha (9.8%) higher and protein was 0.8 g/100 g (7%) higher with spring broadcasting compared to fall broadcasting. This result could be reasonably expected considering that the spring applications are much closer to the time of peak crop uptake; however, in reality, the relative performance of these two practices often varies with the specific environmental conditions. Again, in this particular case, yields with spring broadcast N were similar to those achieved with the fall banded treatments but, for protein, was the spring broadcast N was still at a slight disadvantage (Fig. 6). When fall deep-banding was compared directly to shallow-banding, yields were similar for both options (3690-3721 kg/ha; $P = 0.593$) but there was a substantial protein advantage to deep-banding (13.5% versus 13.0%; $P = 0.001$). This result was consistent with the previous year.

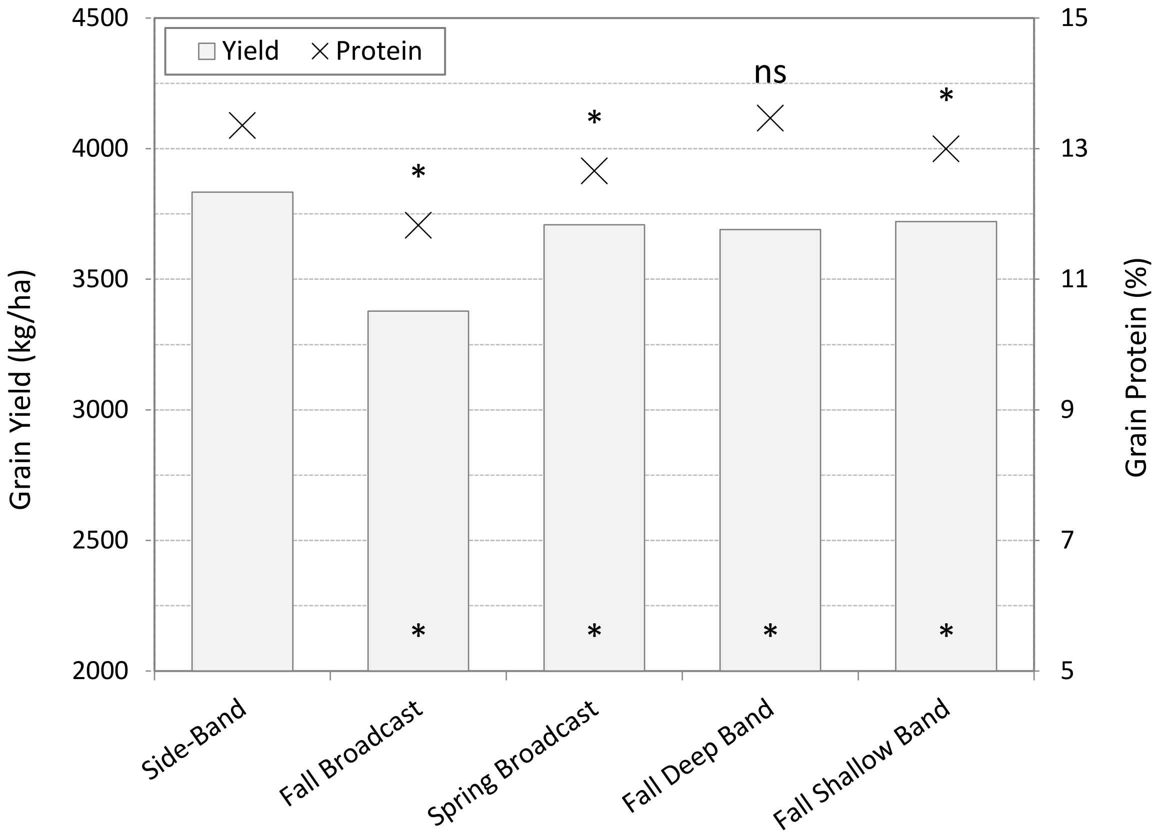

Figure 6. Contrasts comparing spring wheat grain yields and protein with side-banded nitrogen (N) fertilizer to alternative timing and placement options at Indian Head in 2021. All treatments received the 1x rate of 110 kg N/ha (soil + fertilizer) and values are the averages for untreated urea and SUPERU®. An asterisk (*) indicates that the value significantly differed from side-banding while 'ns' indicates that it did not ($P \leq 0.05$).

With only two years of results and significant Yr x Trt interactions for both variables, the averaged results will not be discussed in detail at this time. However, the individual treatment means over the two-year period are provided for yield and protein in Figs. 7 and 8 below and in Tables 6 and 10 of the Appendices. The full set of contrast results for yield and protein when averaged over the two years are provided in Tables 9 and 13 of the Appendices while those comparing the performance of the two-pass seeding/fertilization systems to side-banding are also illustrated in Fig.9.

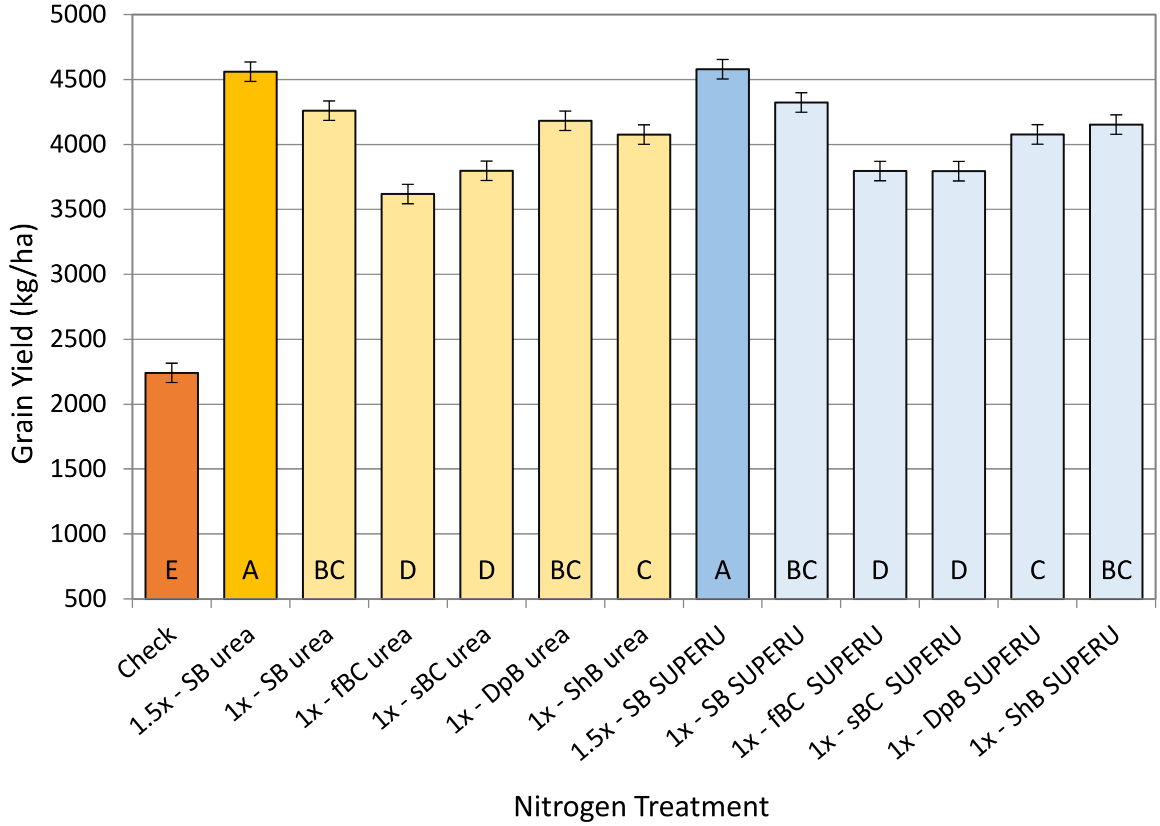

Figure 7. Individual nitrogen treatment means for spring wheat grain yield at Indian Head, averaged over a two-year period (2020 and 2021). Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.

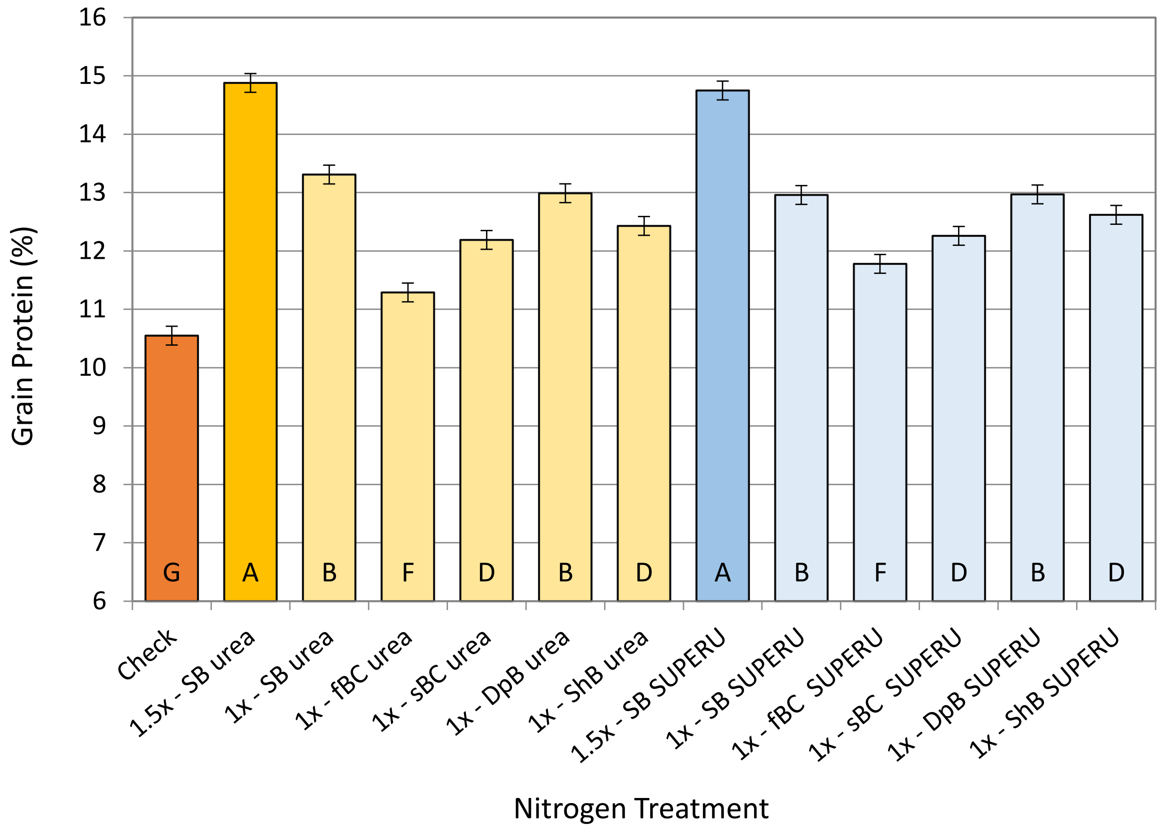

Figure 8. Individual nitrogen treatment means for spring wheat grain protein at Indian Head, averaged over a two-year period (2020 and 2021). Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.

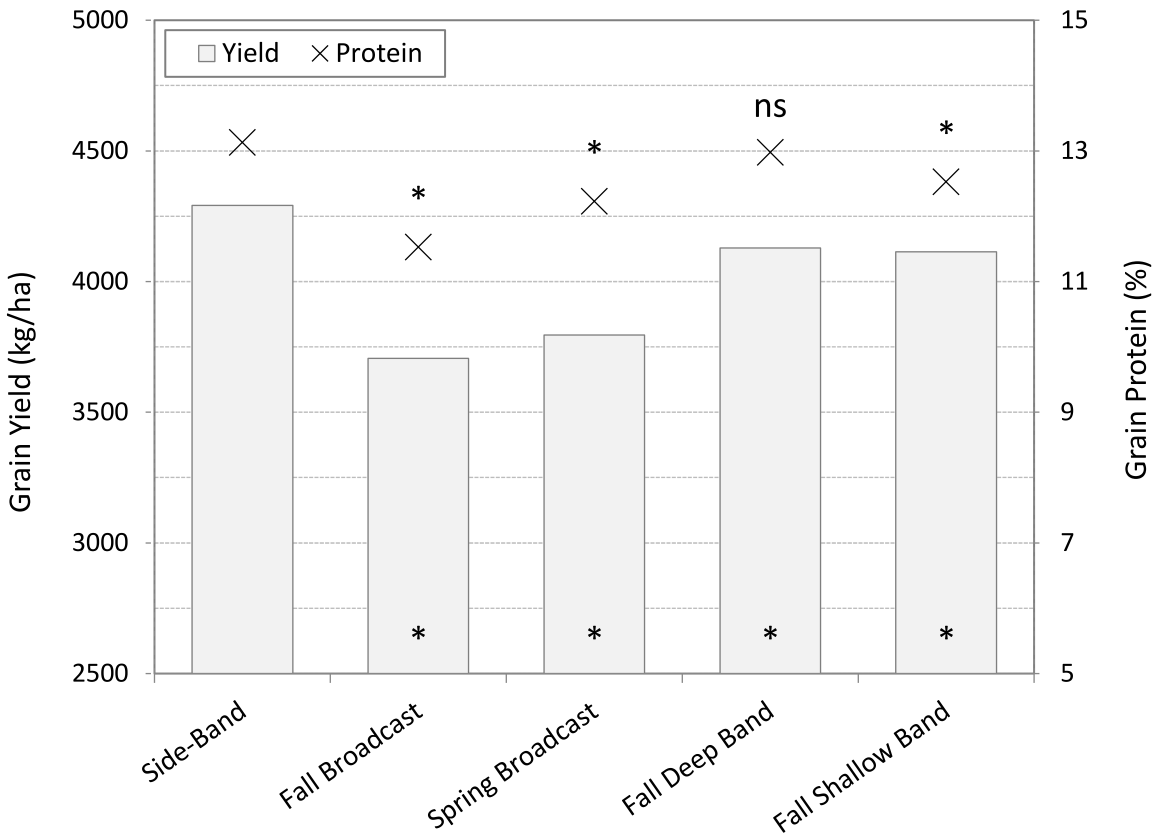

Figure 9. Contrasts comparing spring wheat grain yields and protein with side-banded nitrogen (N) fertilizer to alternative timing and placement options at Indian Head, averaged over a two-year period (2020 and 2021). All treatments received the 1x rate of 110 kg N/ha (soil + fertilizer) and values are the averages for untreated urea and SUPERU®. An asterisk (*) indicates that the value significantly differed from side-banding while 'ns' indicates that it did not ($P \leq 0.05$).

Extension Activities
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 of this work 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). On July 20, 2021, the plots were shown to approximately 70 participants during a scaled back IHARF Crop Management Field Day where there was discussion of 4R N management principles and observations from previous years and other pertinent field trials. 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 reports, past interim reports, other extension materials will be available online through IHARF and/or Agri-ARM websites.

11. Conclusions and Recommendations

This project has demonstrated tremendous overall benefits to N fertilization in addition to the relative efficacy of contrasting N management strategies which were selected to demonstrate certain 4R nutrient management principles. These principles promote providing nutrients in the Right form, at the Right time, in the Right place, and at the Right rate while recognizing the need to adapt to specific agronomic, economic, environmental, and logistic considerations. The premise is to provide nutrients as close to the time of crop uptake as possible, in a formulation and placement that will be relatively safe from losses but available to the crop, and at an adequate but not excessive rate. Achieving these goals will simultaneously maximize the efficiency of the applied N while minimizing the potential for environmental harm and will, ideally, also provide the greatest economic returns. This demonstration contrasted two N formulations (untreated urea and SUPERU®); however, these specific formulations were not intended to represent all available options, nor would they necessarily be considered appropriate for each of the individual timing/placement options evaluated. The management options were tested with N applied at a rate that was adjusted for residual soil nutrients and intended to be slightly less than optimal. The suitability of the 1x rate for our purposes was confirmed with a combination of high N and unfertilized control plots.

With respect to rate, the project demonstrated strong overall responses to N and also showed that 110 kg total N/ha (the 1x rate) was not sufficiently high to maximize yield or protein and, as such, appropriate for detecting differences in environmental N losses and/or availability amongst the timing/placement options. The observed responses to the limited number of rates evaluated was consistent in both years, despite the lower yield potential in 2021.

Regardless of the year, side-banding proved to be the most effective N management strategy evaluated for both formulations, simultaneously resulting in amongst the highest grain yields and protein concentrations. Coming back to the 4R nutrient management principles, side-banding places the N beneath the soil surface where it is relatively protected from NH_3 volatilization, and in concentrated bands which slows both urea hydrolyses and nitrification in addition to immobilization of N. Side-banding aims to place the N far enough away from the seed that it will not negatively impact emergence but close enough that it will still be readily accessible to the crop but less available to shallow rooted weeds growing between crop rows. Next to side-banding, the best options evaluated were fall in-soil bands; however, this practice generally still resulted in lower yields and, to lesser extent, protein, under the specific conditions encountered. In both years, there was a small but significant benefit to deeper placement of the fall-banded N, particularly with respect to protein. Presumably, the deeper placement resulted in the applied N being more protected against volatilization losses and may have also been more readily dissolved and available to the crop compared to shallow-banding. While there was still a strong N benefit observed with surface-broadcasting, these treatments were clearly inferior to side-banding and in-soil banding when both yield and protein were considered. In 2019-20, efficacy with both fall and spring broadcasting was similar; however, the fall application favour yield slightly while the spring application favoured protein. In 2020-21, spring broadcasting was superior to fall banding for both variables by a substantial margin. These differences in the relative response were attributed to the specific environmental conditions. The first year, despite abundant soil moisture, neither the fall nor spring broadcast applications were followed by sufficient precipitation to effectively move the N deeper into the soil where it would be simultaneously more protected from volatilization and available to the crop. The second year, initial soil moisture was extremely low and precipitation following the fall N applications was negligible; thus, leaving the surface applied N stranded and vulnerable to volatilization through a particularly dry fall, winter, and early spring. While the spring broadcast treatments were applied to exceptionally dry soil, 80 mm of precipitation fell within 16 days of the applications and conditions leading up to this event were cool and not generally conducive to high losses of N. It is plausible that even urea hydrolysis was impeded by the extreme dry conditions when the N was first applied; thus, further reducing the potential for NH_3 volatilization to occur. The result of these conditions was that the spring-broadcast N performed far better than the fall-broadcast N; however, neither resulted in the overall efficiency achieved with side-banding. To extrapolate, broadcasting N without incorporation is never ideal but can perform well if timely precipitation moves it into the rooting zone before environmental losses or yield reductions due to N deficiency can occur.

With respect to formulations, the performance of untreated urea and SUPERU® was mostly similar; however, there were important exceptions. Most notably, there was a significant overall advantage to SUPERU® in 2021 which could largely be attributed to the fall broadcast applications. This was the treatment that was expected to be most likely to benefit from a product like SUPERU®, which offers protection against both volatilization and denitrification.

This project was re-established in the fall of 2021 and will be completed for a third growing season.

Supporting Information

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. Special thanks are extended to all of the IHARF staff who worked on the field trials and harvest samples over the two seasons and to Danny Petty for administering the project.

13. Appendices:

Table 4. Selected agronomic information and dates of operations for spring wheat 4R nitrogen demonstration at Indian Head in 2019-20 and 2020-21.

Factor / Field Operation	2019-20	2020-21
Previous Crop	Canola	Canola
Fall N applications	Oct-7-2019	Oct-8-2020
Spring N applications	May-10-2020	May-8-2021
Pre-emergent herbicide	894 g glyphosate/ha May-14-2020	894 g glyphosate/ha May-11-2021
Seeding Date	May-11-2020	May 10-2021
Seed Rate	325 seeds/m^2 (138 kg/ha)	375 seeds/m^2 (152 kg/ha)
Variety	CDC Alida VB	CDC Alida VB
kg P_2O_5-K_2O-S ha^{-1}	35-0-0 (seed-placed MAP)	35-0-0 (seed-placed MAP)
In-crop Herbicide	100 g fluroxypyr/ha + 400 g 2,4-D LV ester/ha + 15 g pyroxsulam/ha (Jun-15-2020)	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-10-2020	100 g prothioconazole/ha + 100 g tebuconazole/ha Jul-6-2020
Pre-harvest herbicide	894 g glyphosate/ha Aug-19-2020	894 g glyphosate/ha Aug-13-2020
Harvest date	Aug-26-2020	Aug-30-2021

Table 5. Model fit statistics and tests of fixed effects for spring wheat grain yield and protein. Heterogeneous estimates of variance components (between years) were permitted and improved the model fit for both response variables.

Variance Components	Yield (kg/ha)	Protein (%)
(between years)	------------ AICc [Z] (smaller is better) ------------	
Homogeneous	1021.01	84.02
Heterogeneous	1018.94	83.44
Source	---------------------- p-values----------------------	
Year (Yr)	0.001	0.039
Treatment (Trt)	<0.001	<0.001
Yr x Trt	<0.001	0.019

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

Table 6. Individual nitrogen (N) management treatment means for spring wheat yield in 2020, 2021, and averaged over the two-years. Values within a column followed by the same letter do not significantly differ (Tukey-Kramer; P ≤ 0.05). The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall Deep Band, ShB is fall shallow band.

#	N Treatment	2020	2021	2-Yr Avg.
		------------------------------ Grain Yield (kg/ha) ---------------------------------		
1	Control (0 N)	2521 e	1962 e	2241 E
2	Urea – 1.5x SB	5142 a	3979 ab	4560 A
3	Urea – 1x SB	4766 b	3753 bc	4260 BC
4	Urea – 1x fBC	3979 d	3257 d	3618 D
5	Urea – 1x sBC	3908 d	3687 bc	3797 D
6	Urea – 1x DpB	4685 bc	3678 bc	4182 BC
7	Urea – 1x ShB	4493 bc	3658 c	4076 C
8	SUPERU – 1.5x SB	5076 a	4083 a	4579 A
9	SUPERU – 1x SB	4731 bc	3915 ab	4323 B
10	SUPERU – fBC	4090 d	3499 cd	3795 D
11	SUPERU – sBC	3856 d	3732 bc	3794 D
12	SUPERU –DpB	4452 c	3703 bc	4077 C
13	SUPERU –ShB	4522 bc	3784 abc	4153 BC
	S.E.M.	135.7	63.7	75.0

Table 7. Predetermined contrast comparisons for spring wheat grain yield at Indian Head in 2020.

Pre-determined Contrast Comparison	Indian Head – 2020 Group A	Group B	Pr > F
	----- Grain Yield (kg/ha) -----		-- p-value --
1.5x N rate (2,8) vs. 1x N rate (3,9)	5109 A	4749 B	<0.001
Urea (2-7) vs. SUPERU (8-13)	4495 A	4454 A	0.215
Side-band (3,9) vs. fall Broadcast (4,10)	4749 A	4035 B	<0.001
Side-band (3,9) vs. spring Broadcast (5-11)	4749 A	3882 B	<0.001
Side-band (3,9) vs. fall Deep Band (6,12)	4749 A	4568 B	0.002
Side-band (3,9) vs. fall Shallow Band (7,13)	4749 A	4507 B	<0.001
Fall Broadcast (4,10) vs Spring Broadcast (5,11)	4035 A	3882 B	0.009
Fall Deep Band (6,12) vs Fall Shallow Band (7,13)	4568 A	4507 A	0.286

Table 8. Predetermined contrast comparisons for spring wheat grain yield at Indian Head in 2021.

Pre-determined Contrast Comparison	Indian Head – 2021		
	Group A	**Group B**	**Pr > F**
	----- Grain Yield (kg/ha) -----		-- p-value --
1.5x N rate (2,8) vs. 1x N rate (3,9)	4031 A	3834 B	<0.001
Urea (2-7) vs. SUPERU (8-13)	3669 B	3786 A	<0.001
Side-band (3,9) vs. fall Broadcast (4,10)	3834 A	3378 B	<0.001
Side-band (3,9) vs. spring Broadcast (5-11)	3834 A	3709 B	0.031
Side-band (3,9) vs. fall Deep Band (6,12)	3834 A	3690 B	0.014
Side-band (3,9) vs. fall Shallow Band (7,13)	3834 A	3721 B	0.050
Fall Broadcast (4,10) vs Spring Broadcast (5,11)	3378 B	3709 A	<0.001
Fall Deep Band (6,12) vs Fall Shallow Band (7,13)	3690 B	3721 B	0.593

Table 9. Predetermined contrast comparisons for spring wheat grain yield, averaged over two years at Indian Head (2020 and 2021).

Pre-determined Contrast Comparison	Indian Head – 2 Year Average		
	Group A	**Group B**	**Pr > F**
	----- Grain Yield (kg/ha) -----		-- p-value --
1.5x N rate (2,8) vs. 1x N rate (3,9)	4570 A	4292 B	<0.001
Urea (2-7) vs. SUPERU (8-13)	4082 A	4120 A	0.106
Side-band (3,9) vs. fall Broadcast (4,10)	4292 A	3706 B	<0.001
Side-band (3,9) vs. spring Broadcast (5,11)	4292 A	3796 B	<0.001
Side-band (3,9) vs. fall Deep Band (6,12)	4292 A	4129 B	<0.001
Side-band (3,9) vs. fall Shallow Band (7,13)	4292 A	4114 B	<0.001
Fall Broadcast (4,10) vs Spring Broadcast (5,11)	3706 B	3796 A	0.030
Fall Deep Band (6,12) vs Fall Shallow Band (7,13)	4129 A	4114 A	0.705

Table 10. Individual nitrogen (N) management treatment means for spring wheat protein in 2020, 2021, and averaged over the two-years. Values within a column followed by the same letter do not significantly differ (Tukey-Kramer; P ≤ 0.05). The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall Deep Band, ShB is fall shallow band.

#	N Treatment	2020	2021	2-Yr Avg.
	Source	------------------------------- Grain Protein (%) ---------------------------------		
1	Control (0 N)	10.42 g	10.69 f	10.55 G
2	Urea – 1.5x SB	14.70 a	15.05 a	14.88 A
3	Urea – 1x SB	13.11 b	13.51 b	13.31 B
4	Urea – 1x fBC	11.11 fg	11.48 e	11.29 F
5	Urea – 1x sBC	11.83 def	12.56 cd	12.19 D
6	Urea – 1x DpB	12.49 bcd	13.49 b	12.99 B
7	Urea – 1x ShB	12.09 cde	12.78 bcd	12.43 D
8	SUPERU – 1.5x SB	14.48 a	15.01 a	14.75 A
9	SUPERU – 1x SB	12.72 bc	13.21 bc	12.96 B
10	SUPERU – fBC	11.36 ef	12.19 de	11.78 F
11	SUPERU – sBC	11.76 def	12.76 bcd	12.26 D
12	SUPERU –DpB	12.49 bcd	13.45 b	12.97 B
13	SUPERU –ShB	12.03 cde	13.22 bc	12.62 D
	S.E.M.	0.279	0.162	0.161

Table 11. Predetermined contrast comparisons for spring wheat protein at Indian Head in 2020.

Pre-determined Contrast Comparison	**Indian Head – 2020**		
	Group A	**Group B**	**Pr > F**
	------ Grain Protein (%) ------		-- p-value --
1.5x N rate (2,8) vs. 1x N rate (3,9)	14.59 A	12.91 B	<0.001
Urea (2-7) vs. SUPERU (8-13)	12.55 A	12.47 A	0.326
Side-band (3,9) vs. fall Broadcast (4,10)	12.91 A	11.24 B	<0.001
Side-band (3,9) vs. spring Broadcast (5-11)	12.91 A	11.79 A	<0.001
Side-band (3,9) vs. fall Deep Band (6,12)	12.91 A	12.49 B	0.004
Side-band (3,9) vs. fall Shallow Band (7,13)	12.91 A	12.06 B	<0.001
Fall Broadcast (4,10) vs Spring Broadcast (5,11)	11.24 B	11.79 A	<0.001
Fall Deep Band (6,12) vs Fall Shallow Band (7,13)	12.49 A	12.06 B	0.003

Table 12. Predetermined contrast comparisons for spring wheat protein at Indian Head in 2021.

Pre-determined Contrast Comparison	Indian Head – 2021 Group A	Group B	Pr > F
	------ Grain Protein (%) ------		-- p-value --
1.5x N rate (2,8) vs. 1x N rate (3,9)	15.03 A	13.36 B	<0.001
Urea (2-7) vs. SUPERU (8-13)	13.14 B	13.31 A	0.051
Side-band (3,9) vs. fall Broadcast (4,10)	13.36 A	11.83 B	<0.001
Side-band (3,9) vs. spring Broadcast (5-11)	13.36 A	12.66 B	<0.001
Side-band (3,9) vs. fall Deep Band (6,12)	13.36 A	13.47 A	0.422
Side-band (3,9) vs. fall Shallow Band (7,13)	13.36 A	13.00 B	0.014
Fall Broadcast (4,10) vs Spring Broadcast (5,11)	11.83 B	12.66 B	<0.001
Fall Deep Band (6,12) vs Fall Shallow Band (7,13)	13.47 A	13.00 B	0.001

Table 13. Predetermined contrast comparisons for spring wheat protein, averaged over two years at Indian Head (2020 and 2021).

Pre-determined Contrast Comparison	Indian Head – 2 Year Average Group A	Group B	Pr > F
	------ Grain Protein (%) ------		-- p-value --
1.5x N rate (2,8) vs. 1x N rate (3,9)	14.81 A	13.13 B	<0.001
Urea (2-7) vs. SUPERU (8-13)	12.85 A	12.89 A	0.483
Side-band (3,9) vs. fall Broadcast (4,10)	13.13 A	11.53 B	<0.001
Side-band (3,9) vs. spring Broadcast (5-11)	13.13 A	12.23 B	<0.001
Side-band (3,9) vs. fall Deep Band (6,12)	13.13 A	12.98 A	0.136
Side-band (3,9) vs. fall Shallow Band (7,13)	13.13 A	12.53 B	<0.001
Fall Broadcast (4,10) vs Spring Broadcast (5,11)	11.53 B	12.23 B	<0.001
Fall Deep Band (6,12) vs Fall Shallow Band (7,13)	12.98 A	12.53 B	<0.001

Abstract

14. Abstract/Summary

A 4R nitrogen (N) management demonstration was initiated near Indian Head, Saskatchewan, in the fall of 2019 and repeated the following season. The test crop was spring wheat; however, our results are applicable to any spring seeded crops that benefit from N fertilization. The treatments were a combination of two formulations (untreated urea and SUPERU®) and six rate/timing/placement combinations (1.5x side-band, 1x side-band, 1x fall broadcast, 1x spring broadcast, 1x fall deep-band, and 1x fall shallow-band), plus an unfertilized control. Rates were adjusted for residual NO_3-N with 110 kg N/ha and 165 kg N/ha (soil plus fertilizer) as the 1x and 1.5x rates, respectively. The response variables of interest were yield and protein. Results for both variables indicated strong responses to N when the fertilized treatments were compared to the control. Comparisons to the 1.5x rate confirmed that the 1x rate was below optimal and, therefore, should enable detection of differences in fertilizer use-efficiency between strategies. Side-banding performed consistently well, simultaneously resulting in the highest yields and protein in both years. Of the two-pass seeding/fertilization systems, fall in-soil banding was the best option but still never performed as well as side-banding when both yield and protein were considered. Deep-banding was preferable to shallow-banding; however, this advantage was more evident in protein than yield. Surface broadcast applications were the least efficient placement option, but the relative performance of fall versus spring broadcasting varied. In 2019-20, fall broadcasting favoured yield while spring broadcasting favoured protein. In 2020-21, spring broadcasting was substantially better than fall-broadcasting by both measures. The two N formulations mostly performed similarly to one another but there were important exceptions. In 2020-21, SUPERU® was advantageous when averaged across timing/placement options but especially with fall broadcasting. The relative performance of these strategies can vary widely with environment; therefore, farmers/agronomists are advised to understand environmental N loss mechanisms and consider options for mitigating those to which they are most vulnerable. This information, along with economic and logistic considerations, will help farmers adopt appropriate N management strategies that are tailored to their operation and the specific environment in which it exists. This demonstration is continuing in 2021-22.