2022 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 #20210956)

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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:** 20210956
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-2021 to February-2023
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, along with 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 under several 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 during the seeding operation was, and still is, seen by many as a 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 a stabilized, enhanced efficiency N source for each of the timing/placement options. The comparison between shallow- and deep-banding was intended to 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 primarily to ensure that sufficient time had passed 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 grain protein concentrations are 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.

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**<u>Methodology and Results</u>**

**9. Methodology:**

A field demonstration with CWRS wheat was initiated with the first N treatments applied in the fall of 2019 followed by subsequent treatment applications and seeding in spring 2020. The project was repeated in 2021 and 2022 growing seasons. The treatments were a combination of six N fertilizer rate/placement/timing strategies and two N fertilizer 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 0.06% N-(n-butyl) thiophosphoric triamide (NBPT; urease inhibitor) and 0.85% dicyandiamide (DCD; nitrification inhibitor). 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. Nitrification inhibitors slow the conversion from $NH_4^+$ to $NO_3^-$, reducing the potential for leaching or denitrification losses to occur. 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 treatments except for 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. Spring wheat nitrogen (N) management treatments evaluated over three growing seasons at Indian Head, Saskatchewan (2020, 2021, and 2022).**

| # | 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 between October 7-13, while the spring broadcast treatments were applied between May 8-11, within approximately 24-48 hours prior to seeding, completed between May 10-12. Nutrients other than N were intended to be non-limiting. The variety was CDC Alida VB in 2020-21 and AAC Wheatland VB in 2022 while the target seeding rate ranged from 325-375 seeds/$m^2$. Weeds were controlled using registered pre-emergent and in-crop herbicides, fungicides were applied preventatively at approximately 50% anthesis. Insecticides were not required in 2020 or 2021; however, grasshoppers were sprayed on July 9 in 2022 (8.9 g deltamethrin/ha). The centre five rows of each plot were straight combined on August 26 (2020), August 30 (2021), or September 6 (2022). 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, prior to any fertilizer applications, and submitted to AGVISE Laboratories (Northwood, ND, USA). Results from these soil test 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 for each plot using cleaned sub-samples and a FOSS NIR analyzer.

Response data from all three years were combined and analyzed using the generalized linear mixed model (GLIMMIX) procedure in SAS® Studio. The effects of year (Y), N treatment (N), and the Y x N interaction were considered fixed and replicate effects (within year) were treated as random. Heterogeneity of variance between years was tested for using the COVTEST statement and the more complex analyses was utilized where heterogeneity was detected. Pre-determined contrasts were used to compare the 1x and 1.5x N rates, the two N fertilizer forms, alternative timing/placement options to side-banding, fall broadcast to spring broadcast, and shallow-banding to deep-banding. The Tukey-Kramer test was used to separate treatment means, either averaged across years or within years. This test controls the experiment-wise error (as opposed to pair-wise) and, as such, is quite conservative. Individual Y x N means were sliced by year so that the multiple comparisons tests would not attempt to compare individual treatment means across years. All treatment effects and differences between means were considered significant at $P \leq 0.05$.

**10. Results:**

*Growing season weather and residual soil nutrients*

Mean monthly temperatures and total precipitation amounts for May-August are presented for each season alongside the long-term (1981-2010) averages in Table 2. Information from the preceding fall months is also provided to coincide with the fall N applications and to aid in the interpretation of results. Soil moisture in the fall of 2019 was abundant with 121 mm of precipitation in September while October, when the fall N fertilizer treatments were applied, was cooler than average. Despite abundant soil moisture, less than 6 mm of total precipitation fell over the two-week period following the fall N applications. Similarly, the following spring (2020) was also dry with less than 2 mm of precipitation over the two-weeks following the N applications. The precipitation following the fall and early spring N applications was not likely sufficient to move the surface applied N into the rooting zone before volatilization losses could occur. 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 fall-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 approximately two weeks of the applications and conditions leading up to this were cool and not conducive to high losses of N. For the final year (2021-22), essentially no rain fell in September; however, October was wetter than normal, and more than 20 mm of precipitation fell within 48 hours of the fall N applications. While this was ideal for reducing N losses, above-normal snowfall, and wet conditions the following spring meant that any nitrate N present in the soil may have been susceptible to environmental losses (i.e., denitrification in particular). The following spring, the abundant snowfall was late to melt and precipitation for the month of May was nearly twice the long-term average with nearly 40 mm of rain falling within 48 hours after the spring N applications and seeding.

**Table 2. Mean monthly temperatures and precipitation amounts along with long-term (1981-2010) averages for the 2020, 2021, and 2022 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%) |
| 2022 | 14.5 | 6.8 | 10.9 | 16.1 | 18.1 | 18.3 | 15.8 (101%) |
| 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%) |
| 2022 | 0.4 | 43.0 | 97.7 | 27.5 | 114.5 | 45.9 | 286 (117%) |
| LT | 35.3 | 24.9 | 51.8 | 77.4 | 63.8 | 51.2 | 244.1 |

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 each year, the trials were established on canola stubble, soil pH for the upper 15 cm was 7.9-8.0, and soil organic matter was 4.6-5.4% (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 16-17 kg N/ha in 2021 and 2022. This was ideal for demonstrating the various N fertilization strategies as it ensured that most 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 field demonstrations completed over three growing seasons at Indian Head, Saskatchewan (2020, 2021, and 2022).**

| 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 |
| 2022 | 0-15 | 7.9 | 5.4 | 7 | 6 | 515 | 11 |
| | 15-60 | 8.2 | – | 10 | – | – | 20 |
| | 0-60 | – | – | 17 | – | – | 31 |

*Crop Responses to Nitrogen Management Treatments*

Table 5 of the Appendices shows model fit statistics and results from the test of common variance which were used to determine whether homogenous or heterogeneous variance estimates would be most appropriate for each response variable. Both yield and protein were affected by year ($P$ < 0.001-0.026) and N treatment ($P$ < 0.001) with significant Y x N interactions detected ($P$ < 0.001). The year effects (Table 7) were such that yields were highest on average in 2022 (4766 kg/ha), followed by 2020 (4325 kg/ha), and 2021 (3591 kg/ha). For protein, values were highest in 2021 (13.03%), lowest in 2020 (12.35%), and intermediate in 2022 (12.43%). Detailed results tables for treatment means and results of the Tukey-Kramer test are deferred to the Appendices but are also provided in the form of simplified figures throughout the report. Because of the significant Y x N interactions, results from individual years are important and will be discussed along with the three-year averages.

In 2020 (Fig. 1; Table 8), all the individual fertilized treatments (3908-5142 kg/ha) yielded higher than the control (2521 kg/ha). The same occurred for protein, with 10.4% in the control versus 11.1-14.7% in the treatments that received supplemental N (Fig. 2; Table 13). The contrasts comparing the 1.5x and 1x N rates (side-band only) in 2020 were also significant ($P < 0.001$) for both yield (5109 kg/ha versus 4749 kg/ha; Table 9) and protein (14.6% versus 12.9%; Table 14). This indicated that the 1x rate was appropriate for detecting differences between N management strategies. When untreated urea and SUPERU® were compared across rates and timing/placement options, no effects were detected for either yield (4454-4495 kg/ha; $P = 0.338$) or protein (12.5-12.6%; $P = 0.297$). Inspection of individual treatment means from 2020 showed that fertilizer effects varied across timing/placement options, but the trends and general performance were similar for both N forms.

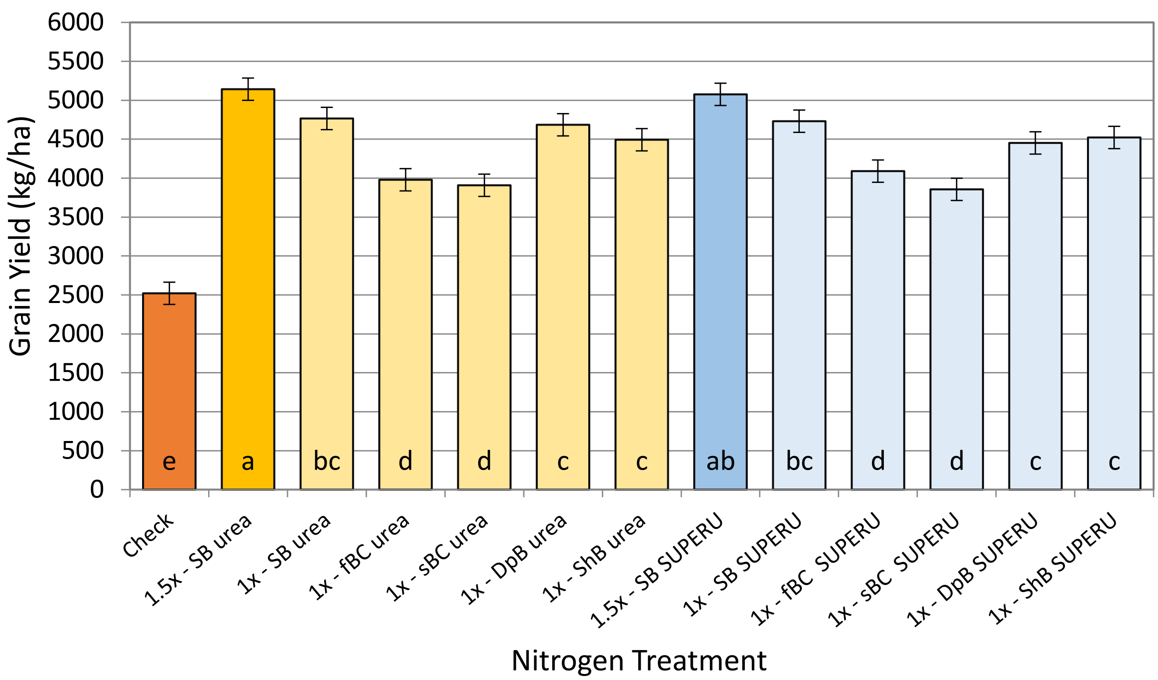


**Figure 1. Individual nitrogen treatment means for spring wheat yield at Indian Head in 2020. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB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

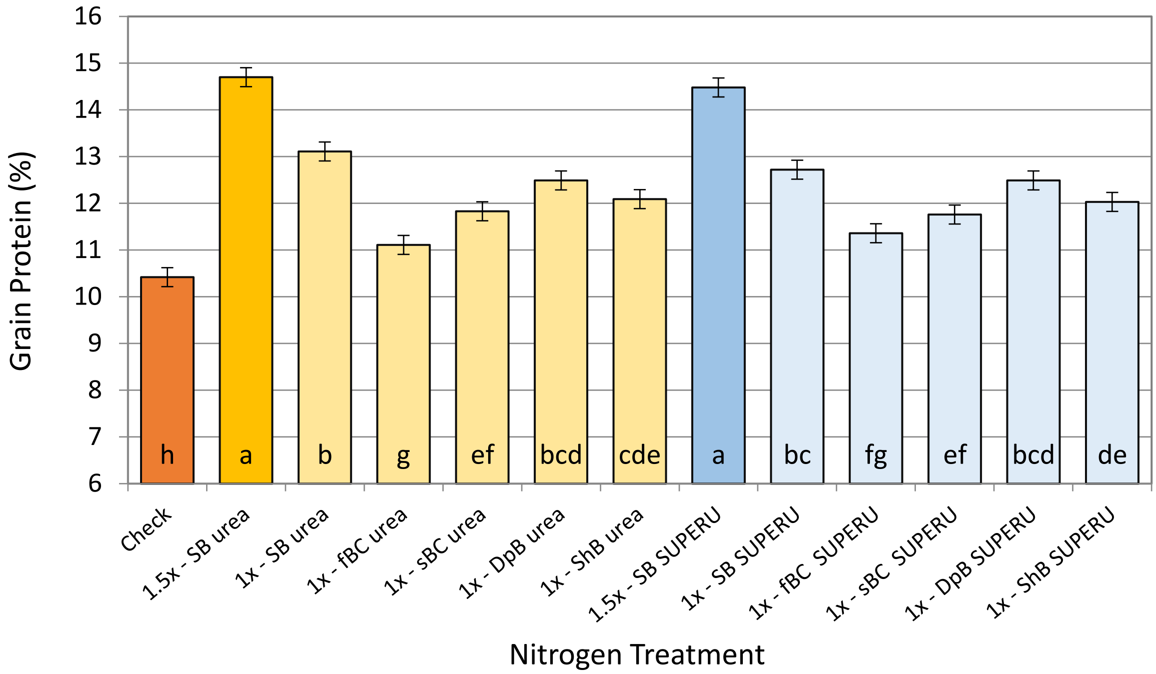


**Figure 2. Individual nitrogen treatment means for spring wheat grain protein concentration at Indian Head in 2020. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is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

To better focus on the relative performance of the timing/placement options compared to side-banding, contrast results for the 2020 season are also presented in Fig. 3. The trends were similar for both variables whereby none of the two-pass seeding-fertilization options performed as well as side-banding; however, there was wide-variation amongst them. First, both in-soil placement options (fall shallow-band and fall deep-band) performed better than the broadcast options. Regardless of timing (fall versus spring), broadcasting the N on the soil surface with no incorporation resulted in substantial yield and protein reductions compared to in-soil banding, especially, side-banding during seeding. 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; $P = 0.041$) 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 to move the applied N into the rooting zone after it was applied. When comparing deep-banding specifically to shallow-banding (across N formulations), yields were similar 4507-4568 kg/ha; $P = 0.410$) but protein was higher with deep-banding (12.5% versus 12.1%; $P = 0.002$) indicating either slightly lower losses or enhanced availability with the deeper placement.

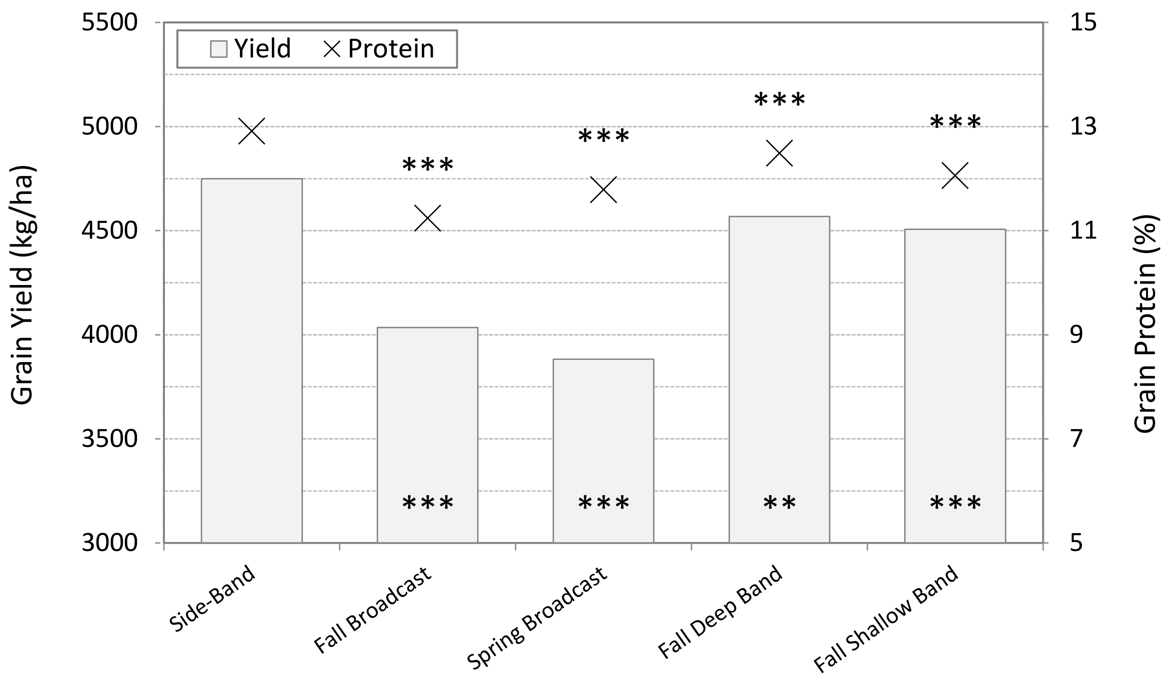


**Figure 3. Contrasts comparing spring wheat yields and protein concentrations achieved with side-banded nitrogen (N) fertilizer to alternative timing and placement options at Indian Head in 2020. All treatments received the 1x rate of 110 kg N/ha (soil + fertilizer) and values are the averages for untreated urea and SUPERU®. Statistical significance is indicated by the following: ns (P > 0.1), * (0.1 > *P* > 0.05), ** (0.05 > *P* > 0.01), and *** (*P* ≤ 0.010).**

Like the previous season, in 2021, all the individual fertilized treatments (3257-4083 kg/ha) yielded significantly higher than the control (1962 kg/ha; Fig. 4). The same was true for protein (10.7% versus 11.5-15.0%; Fig. 5). Again, when averaged across forms, significant differences between N fertilizer side-banded at the 1.5x N rate and the 1x rate were detected for both yield (Table 10; $P$ = 0.009) and protein (Table 15; $P$ < 0.001). 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 ($P$ = 0.007) and protein ($P$ = 0.038) when averaged across 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). Importantly, and as expected, the greatest advantage to SUPERU® occurred with the fall broadcast applications; however, the multiple comparisons test did not find the differences between these individual treatment means to be significant at $P \leq 0.05$. Aside from the differences in response with fall broadcast N, inspection of the individual treatment means showed similar trends for both N formulations despite substantial variation across timing/placement options.

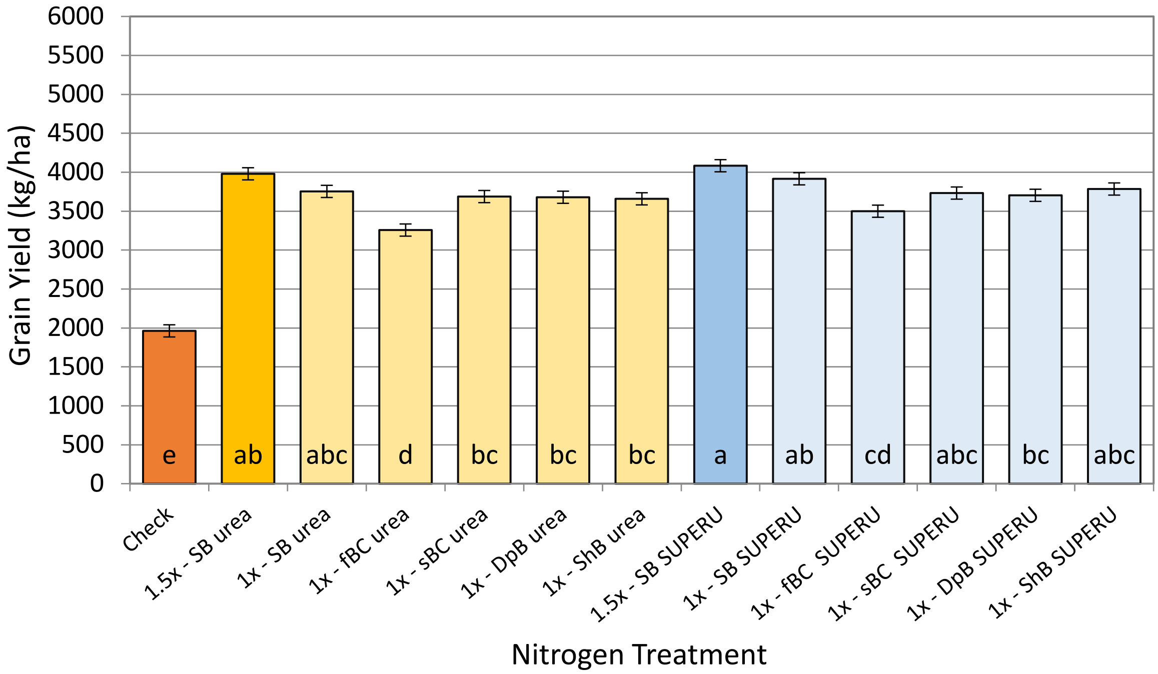


**Figure 4. Individual nitrogen treatment means for spring wheat grain yield at Indian Head in 2021. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast,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

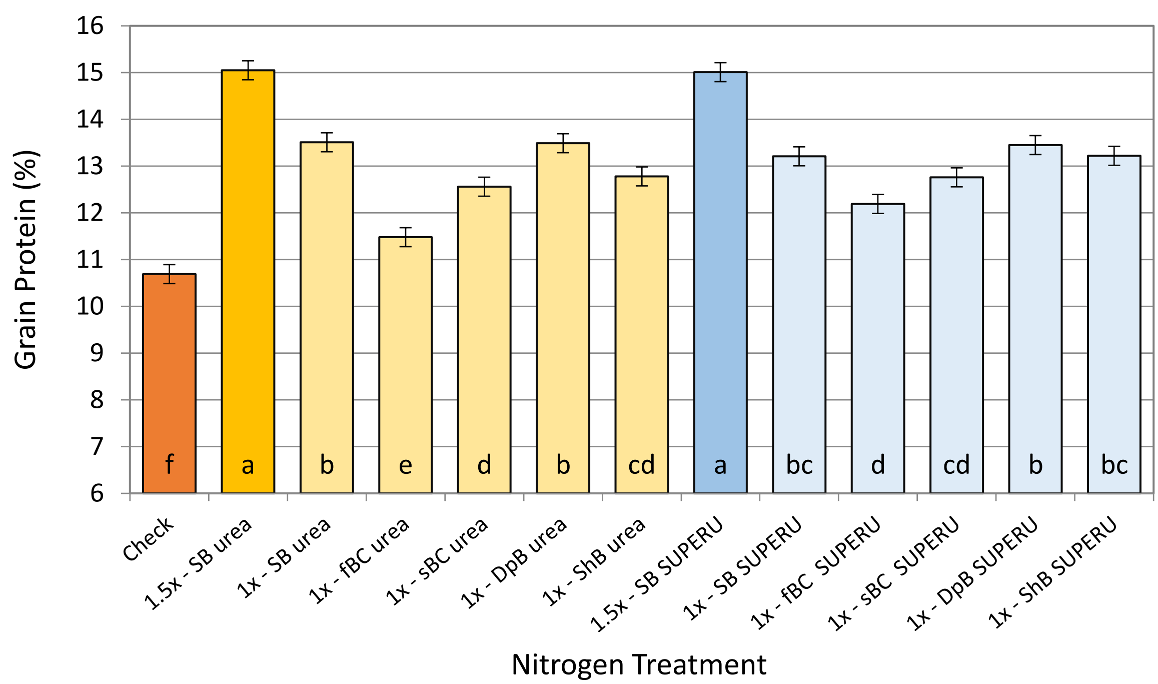


**Figure 5. Individual nitrogen treatment means for spring wheat grain protein concentration at Indian Head in 2021. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is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

Results from the pre-determined contrasts comparing side-banding to each of the two-pass seeding/fertilization systems in 2021 are presented graphically in Fig. 6 below. Aside from the fact that side-banding performed best overall, the efficacy of the various two-pass seeding/fertilization systems differed somewhat relative to the previous year. For yield, the poorest option was fall broadcasting, which resulted in a yield loss of 456 kg/ha ($P < 0.001$) relative to side-banding, despite the use of SUPERU® reducing these losses to a certain extent. Fall banding, regardless of depth, and spring broadcasting resulted in similar yields that trended lower than what was achieved with side-banding (3690-3721 kg/ha versus 3834 kg/ha); however, the loss was not significant at the 5% probability level ($P$ = 0.054-0.127). As previously alluded to, there was a large yield advantage to spring versus fall broadcasting ($P < 0.001$), largely attributable to the timing of precipitation events following the applications. Yields with fall in-soil banding were similar, regardless of fertilizer placement depth ($P = 0.680$). As expected, protein was more responsive to N management than yield and the observed advantage to side-banding was statistically significant over both fall and spring broadcasting ($P < 0.001$) and fall shallow-banding ($P = 0.009$), but not deep-banding ($P = 0.394$). The observed protein advantage to deep (13.5%) versus shallow (13.0%) banding with relatively little difference in yield suggests that environmental losses were less with the deeper fertilizer placement ($P < 0.001$).

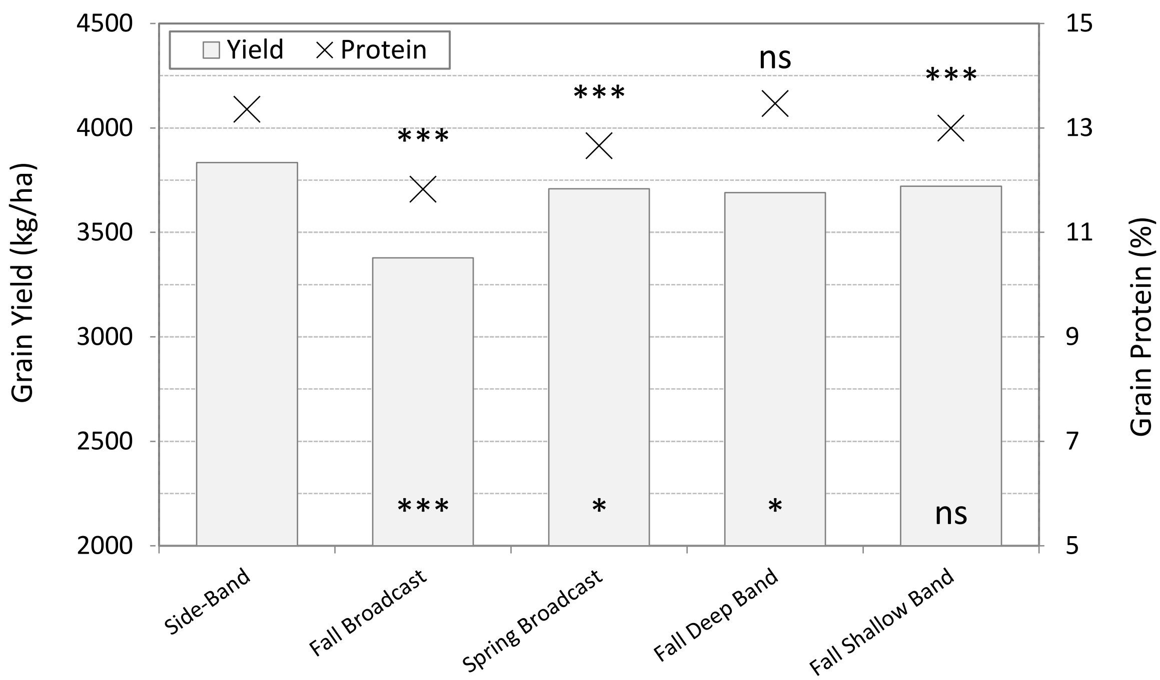


**Figure 6. Contrasts comparing spring wheat grain yields and protein concentrations with side-banded nitrogen (N) fertilizer to alternative timing and placement options at Indian Head in 2021. All treatments received the 1x rate of 110 kg N/ha (soil + fertilizer) and values are the averages for untreated urea and SUPERU®. Statistical significance is indicated by the following: ns (P > 0.1), * (0.1 > $P$ > 0.05), ** (0.05 > $P$ > 0.01), and *** ($P \leq 0.010$).**

In 2022, the third and final year of the demonstration, the results were like the previous two seasons in many respects. The multiple comparisons test indicated that grain yields in the control (2458 kg/ha) were substantially and significantly lower than each individual treatments that received supplemental N fertilizer (4380-5726 kg/ha; Fig. 7). For protein, the trends were similar in that the value was lowest in the control (11.8%); however, this did not significantly differ from most of the treatments that received the 1x N rate (11.9-12.4%; Fig. 8). The higher protein levels in the control may have been due to increased mineralization resulting from to the wet conditions early in the season preceded by an extended dry period. Further to this, protein concentrations at the 100% N rate may have been somewhat hindered by the high yield potential and strong overall response to N. The 1.5x N rate resulted in both higher yields (5631 kg/ha versus 5106 kg/ha; *P* < 0.001; Table 11) and, especially, protein (14.3% versus 12.4%; *P* < 0.001; Table 16). The urea versus SUPERU® comparison in 2022 was not significant for either yield (4967 kg/ha versus 4950 kg/ha; *P* = 0.705) or protein (12.48% versus 12.49%; *P* = 0.910). Like the previous season, there did appear to be a yield advantage to SUPERU® over untreated urea in the fall broadcast applications specifically, but again, these individual treatment means did not significantly differ according to the Tukey-Kramer multiple comparisons test.

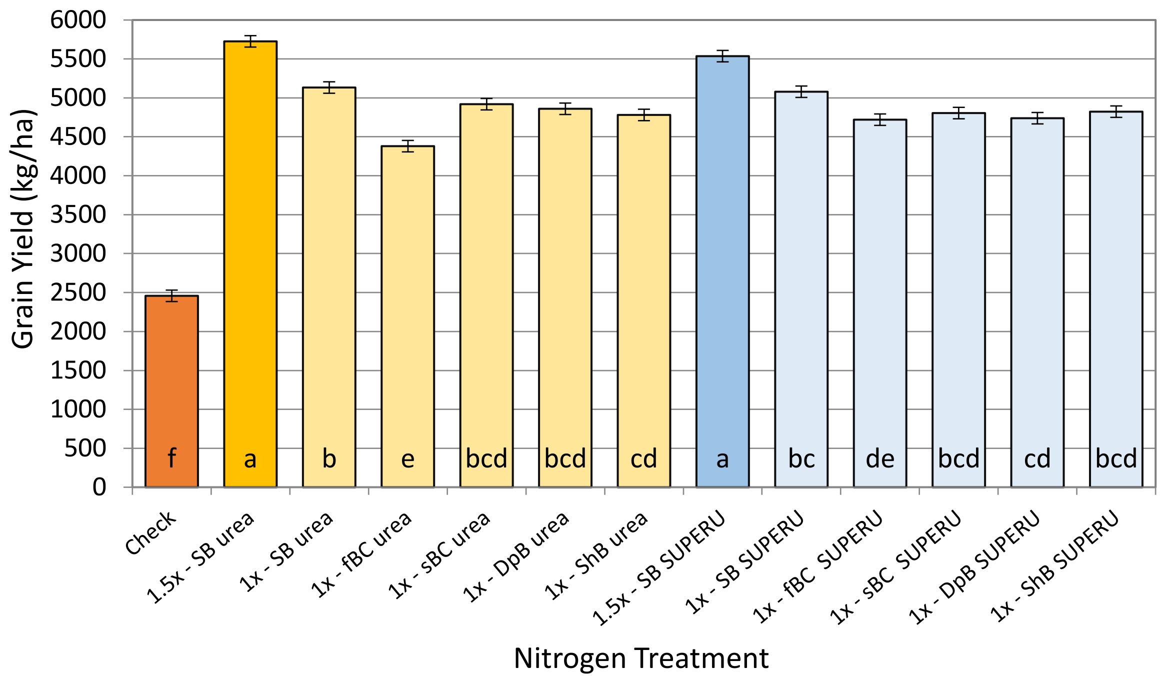


**Figure 7. Individual nitrogen treatment means for spring wheat grain yield at Indian Head in 2022. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.**

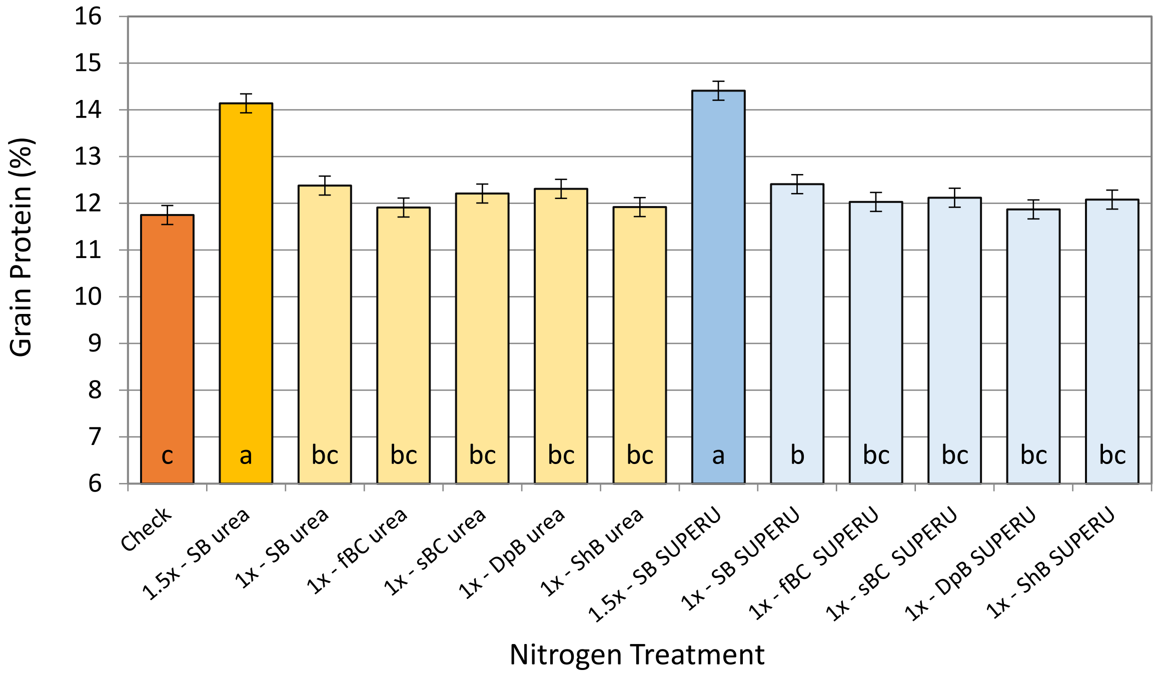


**Figure 8. Individual nitrogen treatment means for spring wheat grain protein concentration at Indian Head in 2022. Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.**

Results from the contrasts comparing side-banding to the two-pass seeding/fertilization systems for 2022 are illustrated in Fig. 9 below. Overall, side-banding resulted in an average yield of 5106 kg/ha with 12.4% protein and was advantageous over each of the two-pass seeding-fertilization options in all respects except protein concentrations achieved with side-banding and spring broadcasting were statistically similar. As alluded to earlier, fall broadcast applications performed the poorest (4550 kg/ha, 12.0% protein), particularly when untreated urea was used as the N source as opposed to SUPERU®. While still poorer than side-banding, precipitation after the spring applications was abundant and timely, thus broadcast applications at this time performed relatively well and resulted in similar or slightly higher yields (4862 kg/ha) and protein (12.2%) than the fall banding applications, regardless of placement depth. Deep versus shallow banding resulted in similar yields (4799-4802 kg/ha; $P = 0.973$) and protein concentrations (12.0-12.1%; $P = 0.504$).

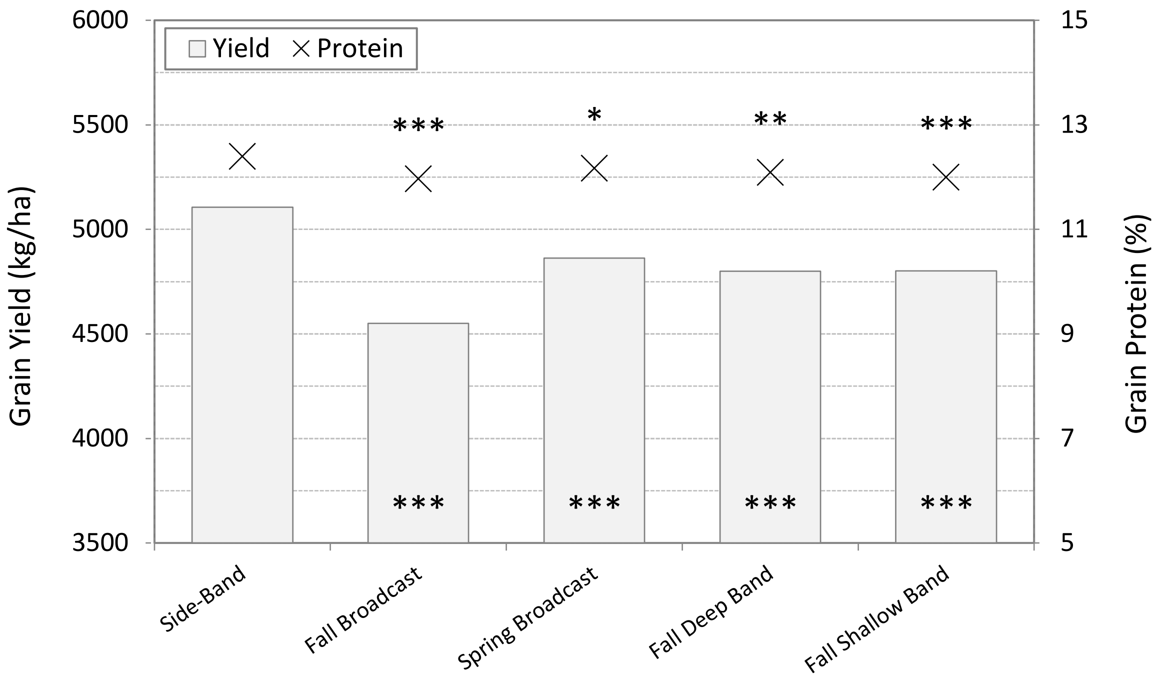


**Figure 9. Contrasts comparing spring wheat grain yields and protein concentrations with side-banded nitrogen (N) fertilizer to alternative timing and placement options at Indian Head in 2022. All treatments received the 1x rate of 110 kg N/ha (soil + fertilizer) and values are the averages for untreated urea and SUPERU®. Statistical significance is indicated by the following: ns (P > 0.1), * (0.1 > *P* > 0.05), ** (0.05 > *P* > 0.01), and *** (*P* ≤ 0.010).**

While the three-year averages do not necessarily reflect specific responses from each individual year, the results were consistent enough to be representative of what might be expected over multiple seasons and a range of conditions. That said, actual responses will vary. Landscape characteristics (i.e., drainage), late fall/early spring soil moisture conditions, and the timing/extent of precipitation following broadcast applications are the most important environmental factors to consider. In addition to the Appendices (Tables 8 and 13), individual treatment means and results of the multiple comparisons tests appear in Figs. 10 and 11 below. The individual treatment means for yield and protein were consistent, showing strong responses to N and side-banding as the preferred placement option. If banding all the N during seeding is not possible or desirable from a logistic perspective, fall banding is the best option and, while not always significantly better, deeper placement is generally preferable for optimizing both yield and protein, if feasible. Fall broadcast was the poorest option but could be improved to some extent with the use of a stabilized N source (i.e., SUPERU®). For yield, the advantage to SUPERU® with fall broadcast applications was statistically significant while, for protein, it was just a trend. Spring broadcasting generally performed better than fall broadcasting but is arguably less practical and still not as effective as fall, in-soil banding.

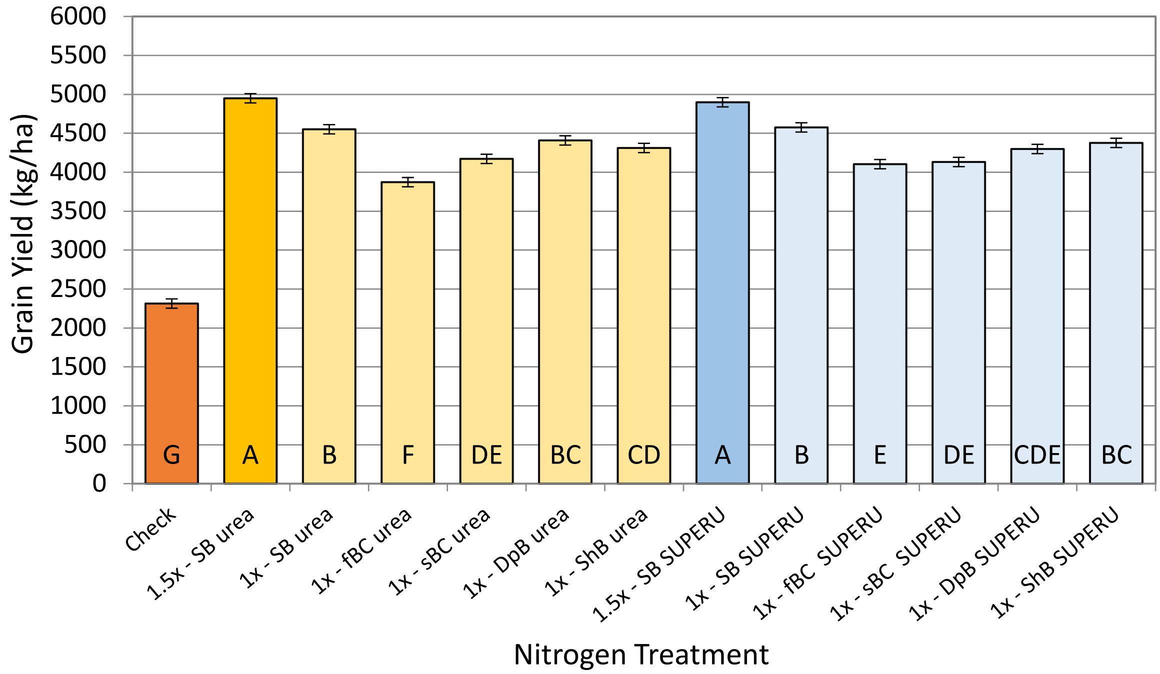


**Figure 10. Individual nitrogen treatment means for spring wheat grain yield at Indian Head, averaged over a three-year period (2020, 2021, and 2022). Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.**

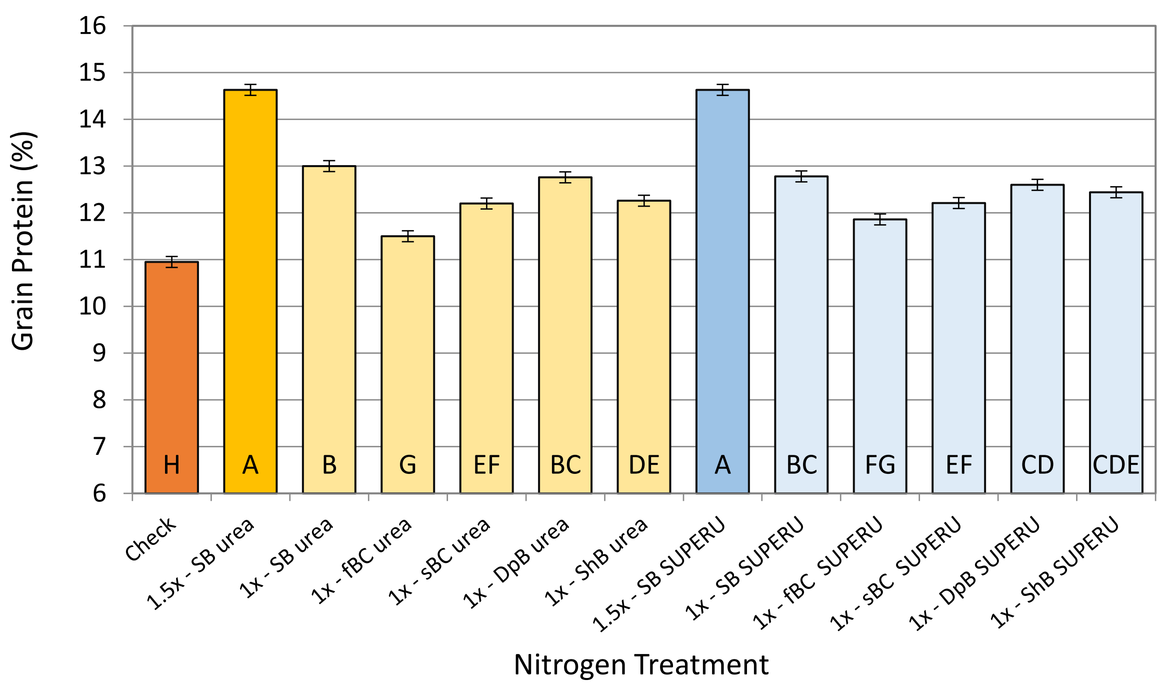


**Figure 11. Individual nitrogen treatment means for spring wheat grain protein concentration at Indian Head, averaged over a three-year period (2020, 2021, and 2022). Error bars are the standard error of the treatment means. The 1x rate is 110 kg N/ha (soil + fertilizer) and the 1.5x rate is 165 kg N/ha. SB is side-band, fBC is fall broadcast, sBC is spring broadcast, DpB is fall deep-band, ShB is fall shallow-band.**

Pre-determined contrast results for the three-year averages are presented in Tables 12 (yield) and 17 (protein) of the Appendices and Fig. 12 below. These comparisons showed higher yields and protein at the 1.5x rate ($P < 0.001$), again indicating that the 1x N was appropriate for evaluating the relative performance of the timing/placement options. Both yields and protein were similar between urea and SUPERU® when averaged across all placement/timing options ($P$ = 0.419-0.500); however, again, there was an advantage to SUPERU® specifically associated with the fall broadcast applications. When averaged across years and N forms, the contrasts showed a statistically significant advantage to side-banding over all two-pass seeding/fertilization systems for both yield ($P < 0.001$) and protein ($P$ < 0.001-0.010). Averaged over years and N forms, increasing the depth of fertilizer placement did not improve yields (4343-4353 kg/ha; $P = 0.827$) but did result in significantly higher protein concentrations (12.7% versus 12.4%; $P < 0.001$).

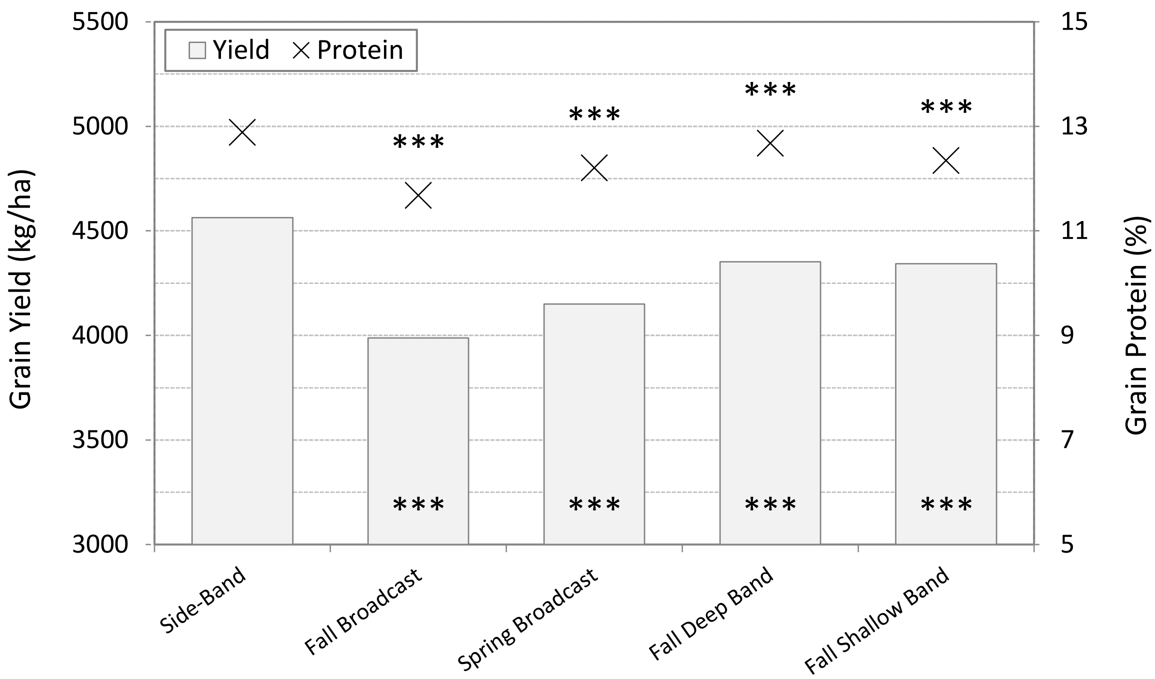


**Figure 12. Contrasts comparing spring wheat grain yields and protein concentrations with side-banded nitrogen (N) fertilizer to alternative timing and placement options at Indian Head, averaged over a three-year period (2020, 2021, and 2022). All treatments received the 1x rate of 110 kg N/ha (soil + fertilizer) and values are the averages for untreated urea and SUPERU®. Statistical significance is indicated by the following: ns (P > 0.1), * (0.1 > *P* > 0.05), ** (0.05 > *P* > 0.01), and *** (*P* ≤ 0.010).**

*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. An in-depth discussion of the project and all results to date was provided to approximately 150 participants each at IHARF Winter Seminar on February 2 (virtual) and the AGVISE Canada meeting at Portage la Prairie on March 17,

2022. The demonstration was scheduled to be shown during the 2022 Indian Head Crop Management Field Day on July 19; however, this event was rained out and moved indoors. In the end, a general overview of the trial was presented to approximately 120 people indoors. Results will continue to be presented where appropriate through oral presentations and other extension materials in the winter of 2022-23 and beyond. This final technical report, past interim reports, other extension materials will be available online through IHARF and/or Agri-ARM websites.

**11. Conclusions and Recommendations**

This project has shown tremendous overall benefits to N fertilization along with 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 also 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, ideally, will 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 that were 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 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 reasonably consistent in all three years, despite the lower yield potential in 2021. In actuality, the optimum rate was likely closer to the 1.5x rate used in this project (165 kg N/ha, soil residual $NO_3$-N plus fertilizer) than the 1x rate (110 kg N/ha, soil residual $NO_3$-N plus fertilizer); however, this could likely vary across geographic locations.

As expected, side-banding proved to be the most effective N management strategy evaluated for both formulations, consistently 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 while also minimizing 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 2/3 years and on average, 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 N being more protected against volatilization losses and may have also been more readily dissolved and available to the crop compared to shallow-banding, particularly under dry conditions. 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 one of three years, the fall application timing favoured yield slightly while the spring application favoured protein. In the other two years, 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 encountered.

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. In 2022, SUPERU® again appeared to be advantageous over untreated urea with the fall broadcast applications. While we do not always see yield and/or protein benefits with enhanced efficiency N products, they are more likely to be realized when either the management practices or environmental conditions are conducive to the pathways of loss which the products protect against. For instance, urease inhibitors are most likely to be beneficial when the potential for volatilization is high (i.e., surface broadcast applications or, to a lesser extent, shallow banding under dry conditions. Nitrification inhibitors are more likely to be beneficial when the risk of denitrification or leaching is highest; therefore, under wet conditions, in depressional areas, or when applied long before crop uptake is expected.

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**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. SUPERU® was provided by Koch Agronomic Services and certain crop protection products were provided in-kind by Corteva and Bayer CropScience. Special thanks are extended to all the IHARF staff who worked on the project over the three growing seasons.

## 13. Appendices:

**Table 4. Selected agronomic information and dates of operations for field demonstrations completed over three growing seasons at Indian Head (2020, 2021, and 2022).**

| Factor / Operation | 2020 | 2021 | 2022 |
|---|---|---|---|
| Previous Crop | Canola | Canola | Canola |
| Fall N applications | Oct-7-2019 | Oct-8-2020 | Oct-13-2021 |
| Spring N applications | May-10-2020 | May-8-2021 | May-11-2022 |
| Pre-emergent herbicide | 894 g glyphosate/ha May-14-2020 | 894 g glyphosate/ha May-11-2021 | 894 g glyphosate/ha May-22-2022 |
| Seeding Date | May-11-2020 | May 10-2021 | May 12-2022 |
| Seed Rate | 325 seeds/$m^2$ | 375 seeds/$m^2$ | 350 seeds/$m^2$ |
| Variety | CDC Alida VB | CDC Alida VB | AAC Wheatland VB |
| kg $P_2O_5$-$K_2O$-S $ha^{-1}$ | 35-0-0 (seed-placed MAP) | 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 | 501 g MCPA ester/ha +129 g fluroxypyr/ha + 90 g clopyralid/ha + 15 g pyroxsulam/ha Jun-12-2022 |
| Foliar Fungicide | 100 g prothioconazole/ha + 100 g tebuconazole/ha Jul-10-2020 | 100 g prothioconazole/ha + 100 g tebuconazole/ha Jul-6-2021 | 100 g prothioconazole/ha + 100 g tebuconazole/ha Jul-11-2022 |
| Pre-harvest herbicide | 894 g glyphosate/ha Aug-19-2020 | 894 g glyphosate/ha Aug-13-2021 | 894 g glyphosate/ha Aug-24-2022 |
| Harvest date | Aug-26-2020 | Aug-30-2021 | Sep-6-2022 |

**Table 5. Model fit statistics and tests of common variance (between years) for selected response variables.**

| Variance Components | Yield (kg/ha) | Protein (%) |
|---|---|---|
| (between years) | ----------------- AICc [Z] (smaller is better) | ----------------- |
| Homogeneous | 1582.30 | 108.54 |
| Heterogeneous | 1576.37 | 108.14 |
| | --------------------------- p-values | --------------------------- |
| Test of Common Variance (Pr > ChiSqu) [Y] | **0.006** | 0.098 |

[Z] Akaike information criterion – used to determine the most appropriate model for each response variable
[Y] P-values greater than 0.05 indicate that variance estimates did not significantly differ across yields

**Table 6. Tests of fixed effects for year (Y), nitrogen (N) treatment, and their interaction (Y x N) for spring wheat grain yield and protein concentrations. Separate variance estimates were permitted between years for yield, but not protein.**

| **Effect** | **Num DF** | **Den DF** | **F-Value** | **Pr > F (p-value)** |
|---|---|---|---|---|
| | ------------------------------ Grain Yield ------------------------------ | | | |
| Year (Y) | 2 | 9 | 480.8 | **<0.001** |
| N Treatment (N) | 12 | 108 | 233.2 | **<0.001** |
| Y x N | 24 | 108 | 8.0 | **<0.001** |
| | ---------------------------- Grain Protein ---------------------------- | | | |
| Year (Y) | 2 | 9 | 5.6 | **0.026** |
| N Treatment (N) | 12 | 108 | 185.5 | **<0.001** |
| Y x N | 24 | 108 | 9.0 | **<0.001** |

**Table 7. Overall year effects on spring wheat grain yield and protein when averaged across nitrogen (N) management treatments. Values in parentheses are the standard error of the treatment means and means within a column followed by the same letter do not significantly differ (Tukey-Kramer; P ≤ 0.05).**

| **Year** | **Grain Yield (kg/ha)** | **Grain Protein (%)** |
|---|---|---|
| 2020 | 4325 B<br>(124.3) | 12.35 B<br>(0.157) |
| 2021 | 3591 C<br>(32.8) | 13.03 A<br>(0.157) |
| 2022 | 4766 (A)<br>(19.0) | 12.43 AB<br>(0.157) |

**Table 8. Individual nitrogen (N) management treatment means for spring wheat grain yield in 2020, 2021, 2022, and averaged over the three-year period. Values within a column followed by the same letter do not significantly differ (Tukey-Kramer; P ≤ 0.05). The 1x rate was 110 kg N/ha (soil + fertilizer) and the 1.5x rate was 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. The P values presented indicate whether the N treatment effect was significant specifically for the corresponding year.**

| # | N Treatment | 2020 | 2021 | 2022 | 3-Yr Avg. |
|---|---|---|---|---|---|
| | | ------ Grain Yield (kg/ha) ------ | | | |
| 1 | Control (0 N) | 2521 e | 1962 e | 2458 f | 2313 G |
| 2 | Urea – 1.5x SB | 5142 a | 3979 ab | 5726 a | 4949 A |
| 3 | Urea – 1x SB | 4766 bc | 3753 abc | 5133 b | 4551 B |
| 4 | Urea – 1x fBC | 3979 d | 3257 d | 4380 e | 3872 F |
| 5 | Urea – 1x sBC | 3908 d | 3687 bc | 4919 bcd | 4171 DE |
| 6 | Urea – 1x DpB | 4685 c | 3678 bc | 4860 bcd | 4408 BC |
| 7 | Urea – 1x ShB | 4493 c | 3658 bc | 4781 cd | 4311 CD |
| 8 | SUPERU – 1.5x SB | 5076 ab | 4083 a | 5536 a | 4898 A |
| 9 | SUPERU – 1x SB | 4731 bc | 3915 ab | 5079 bc | 4575 B |
| 10 | SUPERU – fBC | 4090 d | 3499 cd | 4720 de | 4103 E |
| 11 | SUPERU – sBC | 3856 d | 3732 abc | 4805 bcd | 4131 DE |
| 12 | SUPERU –DpB | 4452 c | 3703 bc | 4739 cd | 4298 CDE |
| 13 | SUPERU –ShB | 4522 c | 3784 abc | 4823 bcd | 4376 BC |
| | S.E.M. | 143.1 | 78.1 | 73.4 | 59.6 |
| | Pr > F (by year) | <0.001 | <0.001 | <0.001 | – |

**Table 9. Pre-determined 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 | 0.338 |
| 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 | 0.016 |
| 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 | 0.041 |
| Fall Deep Band (6,12) vs Fall Shallow Band (7,13) | 4568 A | 4507 A | 0.410 |

**Table 10. Pre-determined 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 | 0.009 |
| Urea (2-7) vs. SUPERU (8-13) | 3669 B | 3786 A | 0.007 |
| 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 A | 0.094 |
| Side-band (3,9) vs. fall Deep Band (6,12) | 3834 A | 3690 A | 0.054 |
| Side-band (3,9) vs. fall Shallow Band (7,13) | 3834 A | 3721 A | 0.127 |
| 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 A | 3721 A | 0.680 |

**Table 11. Pre-determined contrast comparisons for spring wheat grain yield at Indian Head in 2022.**

| Pre-determined Contrast Comparison | Indian Head – 2022 Group A | Group B | Pr > F |
|---|---|---|---|
| | ------- Grain Yield (kg/ha) ------ | | --- p-value --- |
| 1.5x N rate (2,8) vs. 1x N rate (3,9) | 5631 A | 5106 B | <0.001 |
| Urea (2-7) vs. SUPERU (8-13) | 4967 A | 4950 A | 0.705 |
| Side-band (3,9) vs. fall Broadcast (4,10) | 5106 A | 4550 B | <0.001 |
| Side-band (3,9) vs. spring Broadcast (5,11) | 5106 A | 4862 B | 0.001 |
| Side-band (3,9) vs. fall Deep Band (6,12) | 5106 A | 4799 B | <0.001 |
| Side-band (3,9) vs. fall Shallow Band (7,13) | 5106 A | 4802 B | <0.001 |
| Fall Broadcast (4,10) vs Spring Broadcast (5,11) | 4550 B | 4862 A | <0.001 |
| Fall Deep Band (6,12) vs Fall Shallow Band (7,13) | 4799 A | 4802 A | 0.973 |

**Table 12. Pre-determined contrast comparisons for spring wheat grain yield, averaged over three years at Indian Head (2020, 2021, and 2022).**

| Pre-determined | Indian Head – 3 Year Average | | |
|---|---|---|---|
| **Contrast Comparison** | **Group A** | **Group B** | **Pr > F** |
| | ------ Grain Yield (kg/ha) ------ | | --- p-value --- |
| 1.5x N rate (2,8) vs. 1x N rate (3,9) | 4924 A | 4573 B | <0.001 |
| Urea (2-7) vs. SUPERU (8-13) | 4377 A | 4397 A | 0.419 |
| Side-band (3,9) vs. fall Broadcast (4,10) | 4563 A | 3988 B | <0.001 |
| Side-band (3,9) vs. spring Broadcast (5,11) | 4563 A | 4151 B | <0.001 |
| Side-band (3,9) vs. fall Deep Band (6,12) | 4563 A | 4353 B | <0.001 |
| Side-band (3,9) vs. fall Shallow Band (7,13) | 4563 A | 4343 B | <0.001 |
| Fall Broadcast (4,10) vs Spring Broadcast (5,11) | 3988 B | 4151 A | <0.001 |
| Fall Deep Band (6,12) vs Fall Shallow Band (7,13) | 4353 A | 4343 A | 0.827 |

**Table 13. Individual nitrogen (N) management treatment means for spring wheat grain protein in 2020, 2021, 2022, and averaged over the three-year period. Values within a column followed by the same letter do not significantly differ (Tukey-Kramer; P ≤ 0.05). The 1x rate was 110 kg N/ha (soil + fertilizer) and the 1.5x rate was 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. The P values presented indicate whether the N treatment effect was significant specifically for the corresponding year.**

| # | N Treatment | 2020 | 2021 | 2022 | 3-Yr Avg. |
|---|---|---|---|---|---|
| | | ---------------------------------- Grain Protein (%) ------------------------------------ | | | |
| 1 | Control (0 N) | 10.42 h | 10.69 f | 11.75 c | 10.95 H |
| 2 | Urea – 1.5x SB | 14.70 a | 15.05 a | 14.14 a | 14.63 A |
| 3 | Urea – 1x SB | 13.11 b | 13.51 b | 12.38 bc | 13.00 B |
| 4 | Urea – 1x fBC | 11.11 g | 11.48 e | 11.91 bc | 11.50 G |
| 5 | Urea – 1x sBC | 11.83 ef | 12.56 d | 12.21 bc | 12.20 EF |
| 6 | Urea – 1x DpB | 12.49 bcd | 13.49 b | 12.31 bc | 12.76 BC |
| 7 | Urea – 1x ShB | 12.09 cde | 12.78 cd | 11.92 bc | 12.26 DE |
| 8 | SUPERU – 1.5x SB | 14.48 a | 15.01 a | 14.41 a | 14.63 A |
| 9 | SUPERU – 1x SB | 12.72 bc | 13.21 bc | 12.41 b | 12.78 BC |
| 10 | SUPERU – fBC | 11.36 fg | 12.19 d | 12.03 bc | 11.86 FG |
| 11 | SUPERU – sBC | 11.76 ef | 12.76 cd | 12.12 bc | 12.21 EF |
| 12 | SUPERU –DpB | 12.49 bcd | 13.45 b | 11.87 bc | 12.60 CD |
| 13 | SUPERU –ShB | 12.03 de | 13.22 bc | 12.08 bc | 12.44 CDE |
| | S.E.M. | 0.203 | 0.203 | 0.203 | 0.117 |
| | Pr > F (by year) | <0.001 | <0.001 | <0.001 | – |

**Table 14. Pre-determined contrast comparisons for spring wheat grain 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 | 0.297 |
| 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 B | <0.001 |
| Side-band (3,9) vs. fall Deep Band (6,12) | 12.91 A | 12.49 B | 0.002 |
| 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 | 0.002 |

**Table 15. Pre-determined contrast comparisons for spring wheat grain 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 | 0.038 |
| 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 | 0.394 |
| Side-band (3,9) vs. fall Shallow Band (7,13) | 13.36 A | 13.00 B | 0.009 |
| Fall Broadcast (4,10) vs Spring Broadcast (5,11) | 11.83 B | 12.66 A | <0.001 |
| Fall Deep Band (6,12) vs Fall Shallow Band (7,13) | 13.47 A | 13.00 B | <0.001 |

**Table 16. Pre-determined contrast comparisons for spring wheat grain protein at Indian Head in 2022.**

| Pre-determined | Indian Head – 2022 | | |
|---|---|---|---|
| **Contrast Comparison** | **Group A** | **Group B** | **Pr > F** |
| | ------- Grain Protein (%) ------- | | --- p-value --- |
| 1.5x N rate (2,8) vs. 1x N rate (3,9) | 14.28 A | 12.40 B | <0.001 |
| Urea (2-7) vs. SUPERU (8-13) | 12.48 A | 12.49 A | 0.910 |
| Side-band (3,9) vs. fall Broadcast (4,10) | 12.40 A | 11.97 B | 0.002 |
| Side-band (3,9) vs. spring Broadcast (5,11) | 12.40 A | 12.17 A | 0.090 |
| Side-band (3,9) vs. fall Deep Band (6,12) | 12.40 A | 12.09 B | 0.024 |
| Side-band (3,9) vs. fall Shallow Band (7,13) | 12.40 A | 12.00 B | 0.004 |
| Fall Broadcast (4,10) vs Spring Broadcast (5,11) | 11.97 A | 12.17 A | 0.150 |
| Fall Deep Band (6,12) vs Fall Shallow Band (7,13) | 12.09 A | 12.00 A | 0.504 |

**Table 17. Pre-determined contrast comparisons for spring wheat grain protein, averaged over three years at Indian Head (2020, 2021, and 2022).**

| Pre-determined | Indian Head – 3 Year Average | | |
|---|---|---|---|
| **Contrast Comparison** | **Group A** | **Group B** | **Pr > F** |
| | ------- Grain Protein (%) ------- | | --- p-value --- |
| 1.5x N rate (2,8) vs. 1x N rate (3,9) | 14.63 A | 12.89 B | <0.001 |
| Urea (2-7) vs. SUPERU (8-13) | 12.72 A | 12.76 A | 0.500 |
| Side-band (3,9) vs. fall Broadcast (4,10) | 12.89 A | 11.68 B | <0.001 |
| Side-band (3,9) vs. spring Broadcast (5,11) | 12.89 A | 12.21 B | <0.001 |
| Side-band (3,9) vs. fall Deep Band (6,12) | 12.89 A | 12.68 B | 0.010 |
| Side-band (3,9) vs. fall Shallow Band (7,13) | 12.89 A | 12.35 B | <0.001 |
| Fall Broadcast (4,10) vs Spring Broadcast (5,11) | 11.68 B | 12.21 A | <0.001 |
| Fall Deep Band (6,12) vs Fall Shallow Band (7,13) | 12.68 A | 12.35 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 for two more growing seasons. 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, suitable for detecting differences in fertilizer use-efficiency between strategies. Side-banding performed consistently well, consistently resulting in the highest yields and protein. 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 the first year, fall broadcasting favoured yield while spring broadcasting favoured protein. In the following years, spring broadcasting was better than fall-broadcasting by both measures. The two N formulations mostly performed similarly to one another but there were important exceptions. In two of three years and averaged across years, SUPERU® was advantageous over untreated urea specifically with fall broadcasting. The relative performance of the demonstrated N management 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 fertilizer management strategies that are tailored to their operation and environmental conditions.