2018 Research Report

from the

Saskatchewan Wheat Development Commission

Project Title:
Increasing Wheat Protein with a Post Emergent Application of UAN
(ADOPT# 20170386)

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Project Identification

1. **Project Number:** 20170386
2. **Producer Group Sponsoring the Project:** Saskatchewan Wheat Development Commission
3. **Project Location(s):** Yorkton, Indian Head, Outlook, Melfort, Redvers, Swift Current, and Scott Saskatchewan.
4. **Project start and end dates (month & year):** April 2018 to February 2019
5. **Project contact person & contact details:**

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Objectives and Rationale

6. **Project Objectives:**

The objectives of this project are:

- To demonstrate the potential of post-anthesis applied UAN (30 lbs/ac N) to increase wheat grain protein.
- To demonstrate that improvements in grain protein with in-season nitrogen (N) are more likely to occur for more nitrogen deficient wheat (ie: base levels of 70 and 100 lbs/ac of N for comparison).
- To demonstrate greater crop safety (less leaf burn) and potentially greater wheat yields when post-anthesis N is applied in a dribble band vs foliar broadcast (flat fan) sprays.
- To demonstrate the potential for a better yield and protein response to post-emergent N when applied earlier in the season (pre-boot versus anthesis)
- To demonstrate the overall risks and benefits of split-applications versus applying all N at seeding. Split-applications may decrease lodging and increase grain protein; however, the separate applications increase cost and applying the entire amount of N up front may provide greater yield potential. An economic analysis of the two practices will be performed.

7. **Project Rationale:**

Post-emergent application of N fertilizer is one of the only options to increase grain protein during the growing season. Often it is most economical when yield potential is high and soil N is inadequate to maintain high protein levels. Split applications of N have the benefit of supplying higher levels of N without the increased risk of lodging that comes with supplying all the nitrogen at seeding. However, split applications may cause a nitrogen deficiency in high yielding wheat before the second application. Dribble banding mid-season is the most effective way to apply liquid nitrogen while minimizing leaf burn. Dribble banding also minimizes N lost to volatilization. Foliar broadcast sprays can cause significant leaf burning. UAN can be diluted with water 50:50 to reduce leaf burn when foliar spraying. Leaves are not good at absorbing sufficient amounts of nitrogen; absorbing only 4-27%. Foliar sprayed UAN is mostly absorbed through the roots after rainfall events wash the N into the soil. Foliar broadcast spray applications of UAN post-anthesis frequently increase protein, but this practice does not always prove to be economical.

Recently, most work has been targeting the post-anthesis stage for increasing protein in wheat. However, applying N at the boot stage instead of post-anthesis stage has been shown to be more consistent at increasing protein, but it is highly dependent on N supply and weather conditions. The boot application time has a higher probability of response, reduced potential for leaf burn, increased likelihood of precipitation, potential for increased yield and growth stages are easily identifiable.

Methodology and Results

8. Methodology:

The demonstration was setup as a factorial with 4 replicates. The first factor contrasted total nitrogen applied which was either 100 or 130 lbs/ac. The second factor contrasted 4 different means of applying the last 30 lbs N/ac. The last 30 lbs N/ac was either applied as side-banded urea at seeding, UAN dribble banded at pre-boot or post anthesis, or UAN foliar sprayed at post anthesis. An extra treatment of “70 lbs N/ac as side-banded urea” was added to the factorial design so that the impact of late in-crop applications of 30 lbs N/ac on a base rate of 70 N could be determined. All treatments applied are listed below. Plot size varied between locations based on equipment size.

Treatment List

1. 70 lbs N/ac as side-banded urea

2. 100 lbs N/ac as side-banded urea

3. 130 lbs N/ac as side-banded urea

4. 70 lbs N/ac as side-banded urea plus
30 lbs N/ac pre-boot surface dribble-band UAN[1,3]

5. 100 lbs N/ac side-banded urea plus
30 lbs N/ac pre-boot surface dribble-band UAN[1,3]

6. 70 lbs N/ac as side-banded urea plus
30 lbs N/ac post-anthesis foliar spray UAN[2,4]

7. 100 lbs N/ac side-banded urea plus
30 lbs N/ac post-anthesis foliar spray UAN[2,4]

8. 70 lbs N/ac side-banded urea plus
30 lbs N/ac post-anthesis surface dribble-band UAN[2,3]

9. 100 lbs N/ac side-banded urea plus
30 lbs/ac N post-anthesis surface dribble-band UAN[2,3]

[1]Applied late-herbicide timing, pre-boot stage

[2]Applied 7-10 days post-anthesis

[3]Sprayed with dribble band nozzle at 20 ga/ac (10 ga/ac UAN + 10 ga/ac water)

[4]Sprayed with 02 flat fan nozzles at 20 ga/ac (10 ga/ac UAN + 10 ga/ac water)

Table 1. Dates of operations in 2018 for the Increasing Wheat Protein with Post Application of UAN							
	---Date---						
Activity	**Indian Head**	**Melfort**	**Outlook**	**Redvers**	**Scott**	**Swift Current**	**Yorkton**
Pre-seed Herbicide Application	May 11 (Roundup Weathermax 540)	May 18 (Glyphosate & Heat LQ)			May 16 (Glyphosate and Aim)	May 15 (Credit & AIM)	
Seeding	May 8	May 5	May 22	May 8	May 19	May 23	May 4
Emergence Counts	May 25	June 7	June 7	May 30	June 8	June 12	May 24
Dribble banded UAN at pre-boot (trt 4 and 5)	June 23	July 6	July 9	June 20	June 28	June 26	June 13
In-crop Fungicide Application	June 25 (Quilt) July 5 (Prosaro)	July 13 (Caramba)		N/a	July 27 (Headline)	N/a	June 25 (Caramba)
In-crop Herbicide Application	June 7 (Buctril M/Simplicity GoDRI)	June 14 (Prestige XC)	June 13 (Buctril M/Simplicity Go Dry)	May 28	June 18 (Butril M and Axial)	June 19 (Tracos and Occtain)	June 6 Prestige followed later with Axial
Dribble band UAN at 7-10 days post-anthesis	July 12	July 24	July 25	July 13	July 19	July 16	July 5
Foliar spray UAN at 7-10 days post-anthesis	July 12	July 24	July 25	July 13	July 19	July 16	July 5
Leaf Burn: % of flag leaf damaged by UAN	July 20	Aug 6	July 27		July 5, 12, 26 and Aug 2	July 25	July 13
Lodging Ratings	Aug 12	Sept 20	Aug 9	Aug 20		N/a	
Pre-harvest Herbicide Application	Aug 9 (Roundup Weathermax 540)				Sept 8	N/a	N/a
Harvest	Aug 14	Oct 4	Aug 17	Aug 21	Sept 28	Aug 27	Aug 29

9. Results:

Growing Season Weather

The summer of 2018 was warmer than normal and seasonal precipitation was below the long-term average at all locations (Tables 2 and 3). Conditions were particularly dry at Indian Head and Outlook where precipitation was only 61, and 42% of the long-term average. Of course this was not an issue at Outlook as the trial was under irrigation. Conditions were better at Melfort, Scott and Yorkton where precipitation was 87, 85 and 72% of the long-term average. Scott experienced hail (July 21) and heavy winds (157 km/hr on June 9) which may have slightly affected crop yield and protein.

Table 2. Mean monthly temperatures along with long-term (1981-2010) normals for the 2018 growing seasons at Melfort, Indian Head, Outlook, Redvers, Swift Current, Scott and Yorkton in Saskatchewan.

Location	Year	May	June	July	August	Avg. / Total
		-------------------------*Mean Temperature (°C)*				---------------------
Melfort	2018	13.9	16.8	17.5	15.8	16.0
	Long-term	***10.7***	***15.9***	***17.5***	***16.8***	***15.2***
Indian Head	2018	13.9	16.5	15.4	17.6	15.8
	Long-term	***10.8***	***15.8***	***18.2***	***17.4***	***15.6***
Outlook	2018	14.8	17.4	18.5	17.5	17.1
	Long-term	***11.5***	***16.1***	***18.9***	***18.0***	***16.1***
Redvers	2018	15.2	18.3	18.6	17.8	17.5
	Long-term	-	-	-	-	-
Scott	2018	13.6	16.6	17.5	15.9	15.9
	Long-term	***10.8***	***14.8***	***17.3***	***16.3***	***14.8***
Swift Current	2018	14.6	16.6	18.8	18.7	17.3
	Long-term	***10.9***	***15.4***	***18.5***	***18.2***	***15.8***
Yorkton	2018	13.9	17.6	18.3	18.1	17.0
	Long-term	***10.4***	***15.5***	***17.9***	***17.1***	***15.2***

Table 3. Precipitation amounts along with long-term (1981-2010) normals for the 2018 growing seasons at Melfort, Indian Head, Outlook, Redvers, Swift Current, Scott and Yorkton in Saskatchewan.

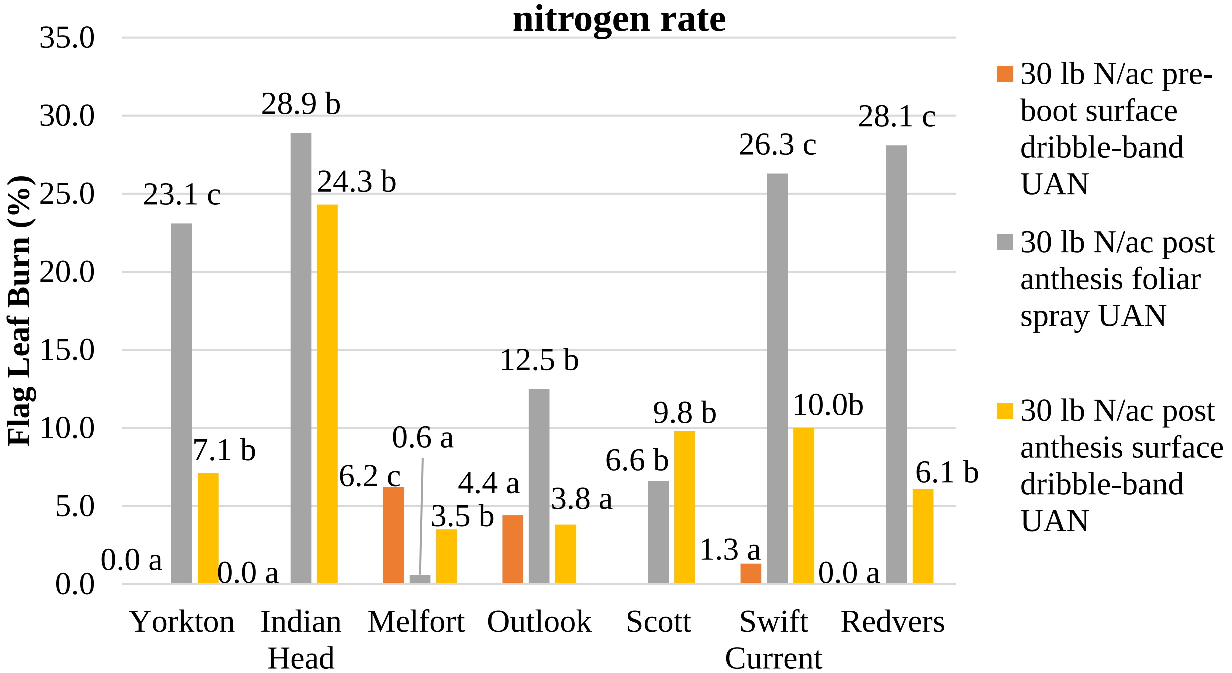
Location	Year	May	June	July	August	Avg. / Total
		-------------------------- *Precipitation (mm)* -------------------------				
Melfort	2018	38.5	46.6	69.5	43.2	196.8
	Long-term	***42.9***	***54.3***	***76.7***	***52.4***	***226.3***
Indian Head	2018	23.7	90	30.4	3.9	148
	Long-term	***49***	***77.4***	***63.8***	***51.2***	***241.4***
Outlook	2018	24.9	12.9	35.2	12.6	85.6
	Long-term	***42.6***	***63.9***	***56.1***	***42.8***	***205.4***
Redvers	2018	21.1	137.2	48.3	9.9	216.5
	Long-term	-	-	-	-	-
Scott	2018	29.6	58	85.8	20.2	193.6
	Long -term	***38.9***	***69.7***	***69.4***	***48.7***	***226.7***
Swift Current	2018	25.6	16.9	51.2	31.0	124.7
	Long-term	***48.5***	***72.8***	***52.6***	***41.5***	***215.4***
Yorkton	2018	0.8	120.1	53.8	21.1	196.1
	Long-term	***51***	***80***	***78***	***62***	***272***

Tables 4 to 15 showing the complete analysis for the study can be found in the appendices.

Crop emergence was lower at Scott, Swift Current and Melfort where average populations were 188, 172 and 202 plants/m^2, respectively (data not shown). At Swift Current, increasing nitrogen rate at seeding from 70 to 100 lbs N/ac significantly reduced emergence from 187 to 157 plants/m^2. This trend was also apparent at Melfort where increasing N reduced emergence from 222 to 181 plants/m^2, respectively. Crop emergence was higher at Yorkton, Indian Head, Outlook and Redvers where average populations were 375, 240, 302 and 303 plants/m^2, respectively (data not shown). At these locations, increasing nitrogen rates at seeding had little effect on emergence. Lodging was very low at all sites and no treatment difference were detected (data not shown).

Significant leaf burn from the application of UAN was observed at all locations when evaluated 1 to 2 weeks after the post-anthesis application (Table 10). As expected, dribble banding UAN pre-boot resulted in significantly less flag leaf burn than dribble banding post-anthesis at Yorkton, Indian Head, Swift Current and Redvers (Table 11 and Figure 1). This is because the flag leaf was not fully emerged when applications occurred pre-boot. When applied post-anthesis, foliar sprayed UAN resulted in more leaf burn than dribble banding at Yorkton, Indian Head, Outlook, Swift Current and Redvers because of increased coverage on foliage. In this study, all in-crop UAN was diluted 1:1 with water with the intention of reducing leaf burning. However, in practice, dribble band applications of UAN are not typically diluted with water and how doing so might affect leaf burn uncertain. It is conceivable that dilution might even make dribble bands more damaging by reducing surface tension and decreasing the number of drops that roll off leaf surfaces (Stu Brandt personal communication). That being said, foliar spray applications were still more injurious in this study than dribble band applications, when both were applied post anthesis.

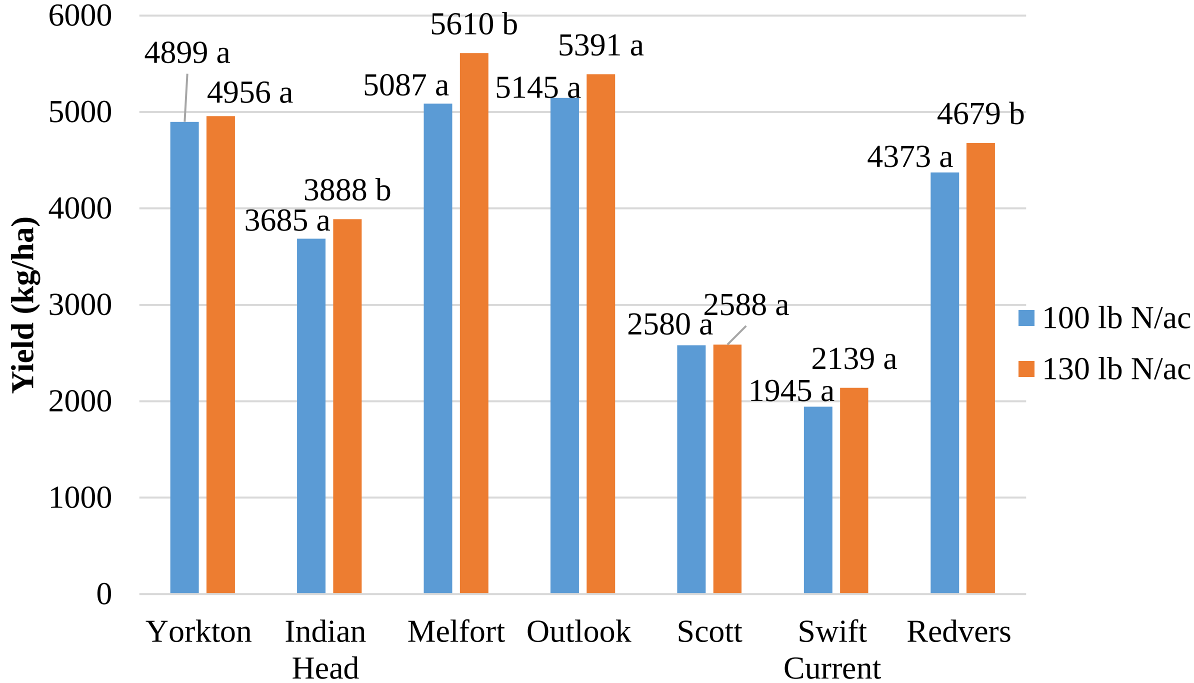
Figure 1. Flag leaf burn from UAN, averaged over total nitrogen rate

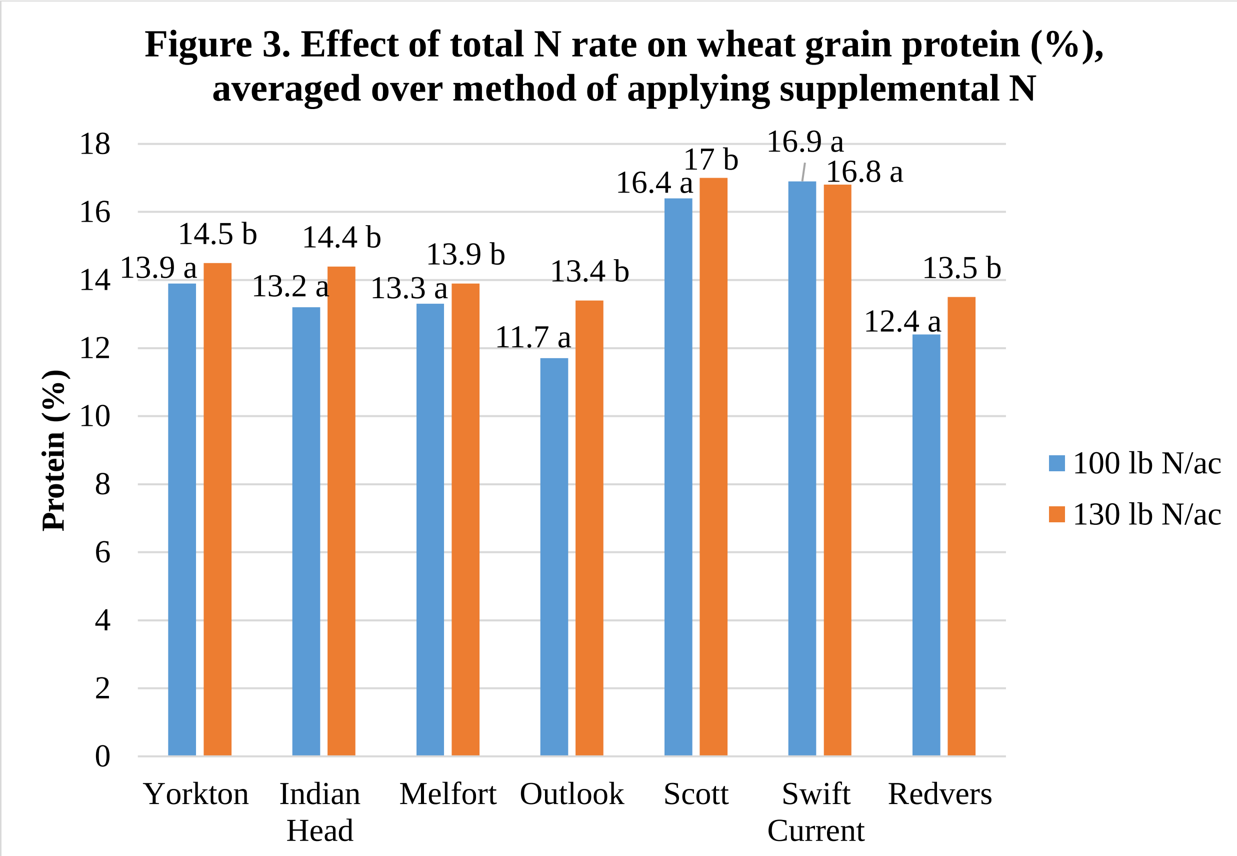


The yield and % protein data for this study have been analysed in two ways. First, as single factor RCBD (Tables 6 and 9) so that treatment 1 can be part of the statistical comparisons and secondly as a two order factorial (trts 2-9) to gain greater power to separate main effect means (Tables 4, 5, 7 and 8). The main effect comparison are total N (100 vs 130 lbs/ac), when averaged over method of applying supplemental N and method of applying supplemental N, when averaged over total N.

Results were fairly similar between locations. Yield and protein increased numerically at all locations as the rate of side-banded urea was increased from 70 to 130 lbs N/ac at seeding (Tables 6 and 9). Overall, the main effect of increasing total nitrogen from 100 to 130 lbs /ac increased yield and protein at all locations with yield differences being statistically significant at Indian Head, Melfort and Redvers (Tables 4, 5 and Figure 2) and protein differences being significant at all locations except Swift Current (Tables 7, 8 and Figure 3). When averaged across location and method of applying supplemental N, increasing total N from 100 to 130 lbs/ac increased protein levels by 0.8%.

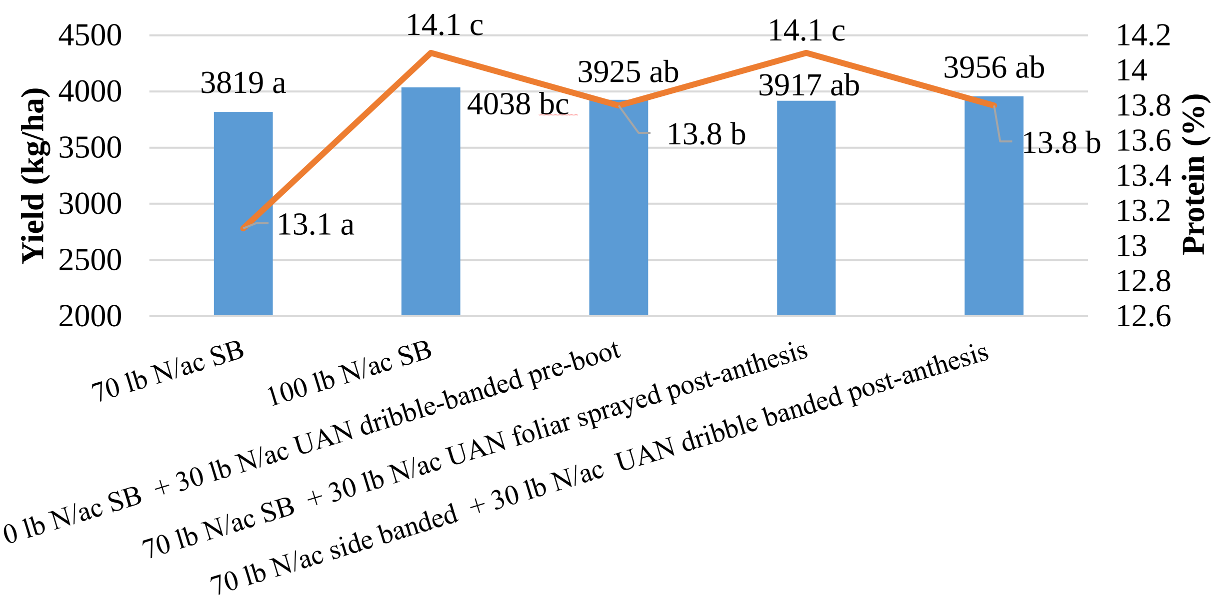
Figure 2. Effect of total nitrogen rate on wheat yield, averaged over method of applying supplemental N

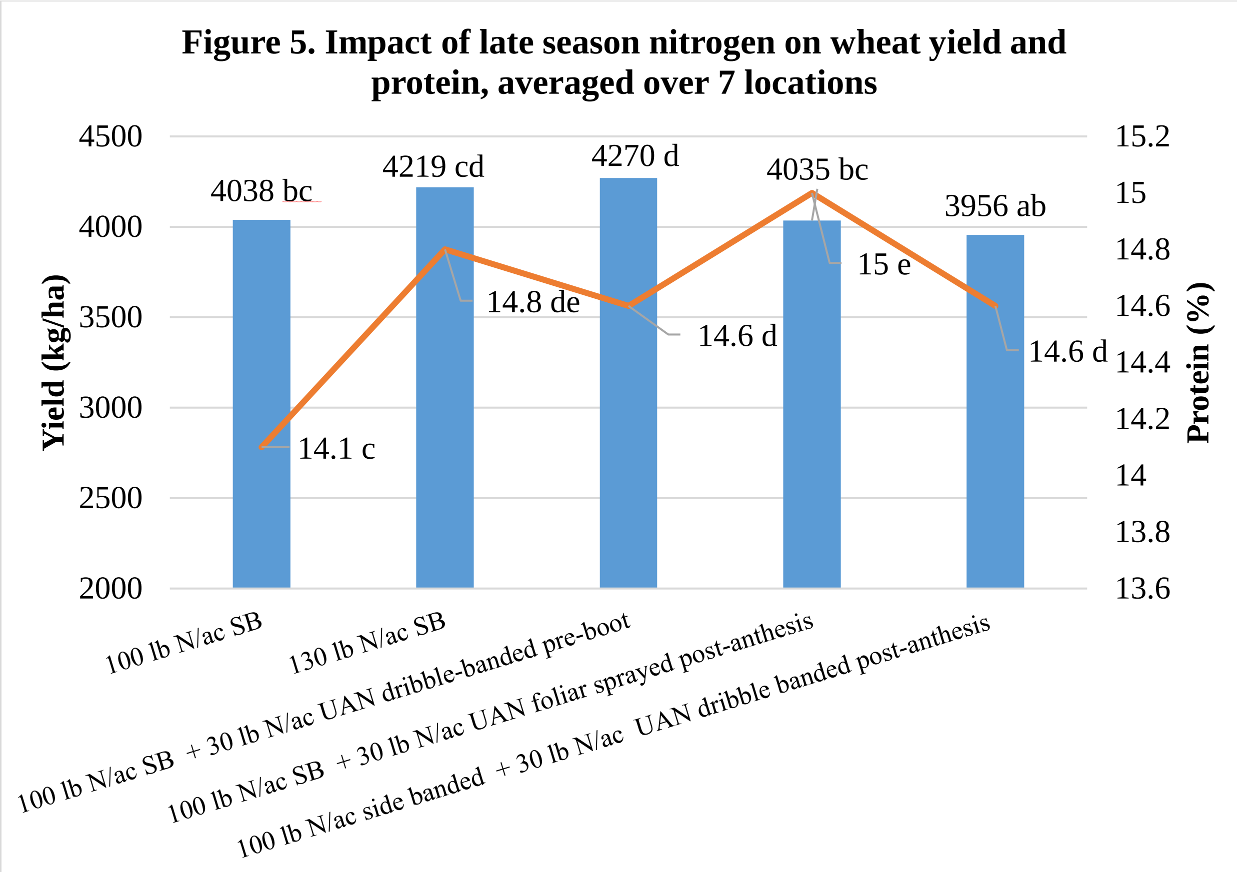




A late season application of 30 lbs N/ac tended to increase yield and often significantly increased percent grain protein. However, late season applications of N did not increase yield or protein relative to side-banding the whole amount of nitrogen at seeding. In other words, it was better to place all the nitrogen down at seeding instead of split applying it. When averaged over location, a late season application of 30 lbs N/ac to a base rate of either 70 or 100 lbs N/ac of side banded urea, increased yield somewhat and significantly increase grain protein (Tables 6 and 9, Figures 4 and 5). Most of the yield increases were not statistically significant, except for a 6% yield increase from dribble banding UAN at the pre-boot stage to a base rate of 100 lbs N/ac (Figure 5). Applications of UAN at the pre-boot are more likely to show a yield increase because the staging is earlier, and less likely to burn the flag leaf. On average, a late season application of 30 lbs N/ac significantly increased protein by 0.8% when applied to a base rate of 70 lbs N/ac and by 0.6% when applied to a base rate of 100 lbs N/ac. This supports the hypothesis that greater protein gains can be achieved from applying late season N to a more N deficient crop of wheat. The protein responses in this study from a late season application of 30 lbs N/ac is very similar to the results of past studies conducted by John Heard, Amy Mangin, Ross MacKenzie and Guy Lafond which have typically observed protein increases of 0.5 to 1% in western Canada.

Figure 4. Impact of late season nitrogen on wheat yield and protein, averaged over total N and locations





While an extra 30 lbs N/ac applied in late season did increase protein, it did not significantly increase yield or protein when compared to side-banding all the N at seeding for any location (Tables 4, 5, 7, 9 Figures 6 and 7). It was more efficient to place all the nitrogen down at seeding instead of split applying it, especially since split applications actually resulted in either less yield or protein in some instances. Even when yield and protein were considered together as kg/ha of protein, split applications never provided a statistically significant advantage over applying the whole amount of nitrogen down at seeding (Tables 13 and 14 Figure 8). The nitrogen from split applications was less efficient as it may have been lost to the atmosphere, stranded on the soil surface or caused crop injury. When comparing between applications of UAN averaged over location, foliar sprays resulted in greater grain protein (Figures 4 and 5). However, this bump in protein may have been partly due to the tendency for lower yield caused by greater leaf burn from foliar spray applications compared to dribble bands. In the end, none of the late season applications provided any yield or protein benefit compared to side-banding all the nitrogen at seeding. It should be acknowledged that our results may have differed under wet conditions where there would be greater potential for denitrification losses in side- or mid-row banded N and less potential for the volatilization losses and/or leaf-burn associated with the in-crop applications.

When averaged over location and method of application, 30 lbs N/ac applied in late season to a base rate of 70 lbs N/ac increased grain protein from 13.1 to 13.9% and yield from

3819 to 3932 kg/ha. This is 0.8% protein increase on roughly a 58 bu/ac crop of wheat. The economics of this situation can be explored by referring to Figure 9. In Figure 9 there are two tables showing the protein spread (cents/%/bu) required to break even from the cost of applying 30 lbs N/ac of UAN plus the cost of application. The left and right hand tables assume a protein increase of 0.5 and 1.0% resulting from the late season application of UAN. This covers the range of results that might be expected based on both the current demonstration and previously reported responses. In each table you will note the spread required to cover costs increases as the price of N increases and it decreases as the yield of wheat increases. Based on the results for this study we would require a spread between roughly 35 and 60 cents/%/bu to breakeven depending of the price of nitrogen. This would be achievable for some years, but predicting those high protein spreads in advance may be difficult. Of course, the most economic scenario in this study was to put all the nitrogen down at seeding, as split applications could not improve yield or protein over this approach.

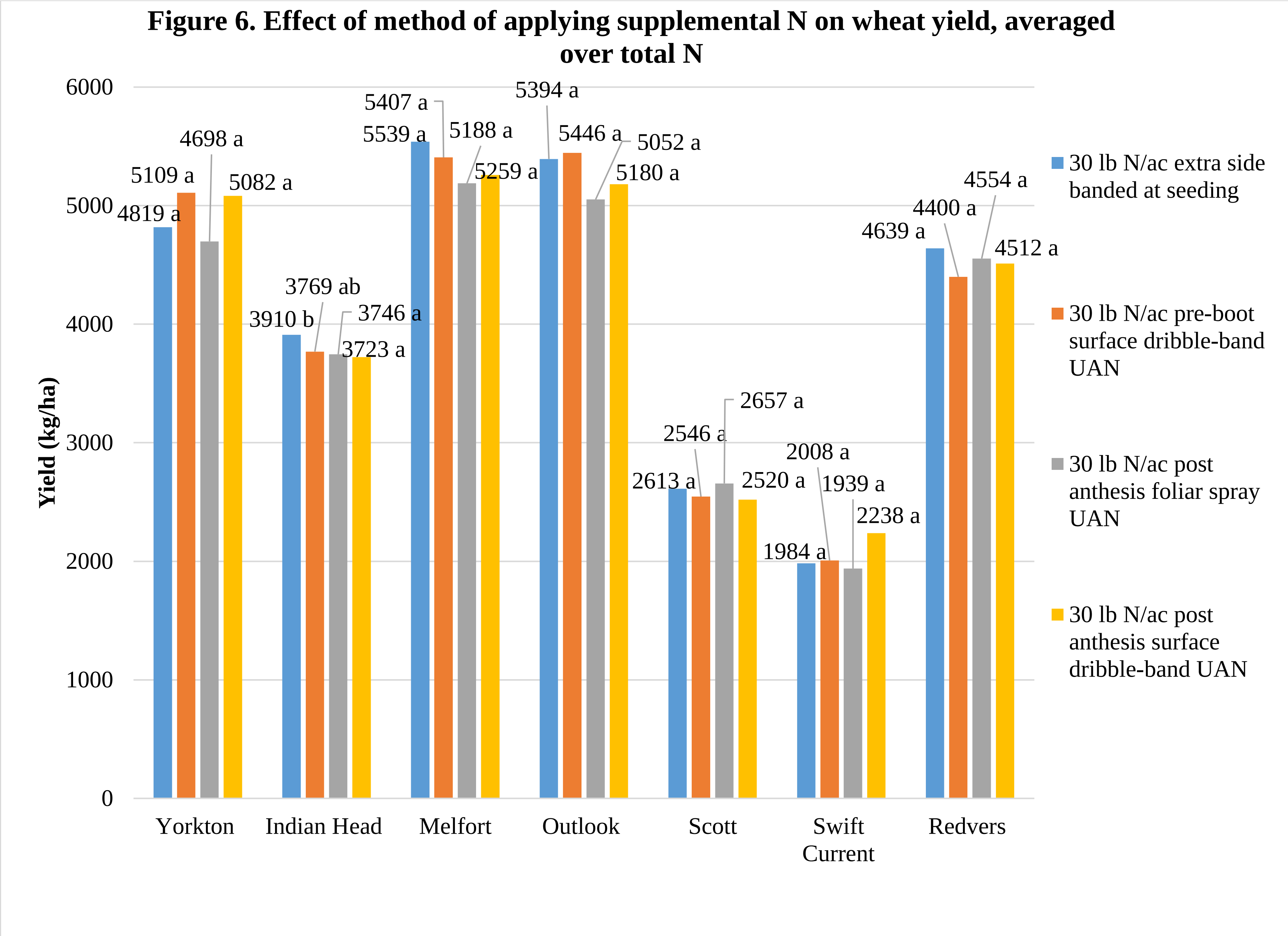


Figure 6. Effect of method of applying supplemental N on wheat yield, averaged over total N
Yield (kg/ha)
6000
5000
4000
3000
2000
1000
0
Yorkton
Indian Head
Melfort
Outlook
Scott
Swift Current
Redvers
4819 a
5109 a
4698 a
5082 a
3910 b
3769 ab
3746 a
3723 a
5539 a
5407 a
5188 a
5259 a
5394 a
5446 a
5052 a
5180 a
2613 a
2546 a
2657 a
2520 a
1984 a
2008 a
1939 a
2238 a
4639 a
4400 a
4554 a
4512 a
30 lb N/ac extra side banded at seeding
30 lb N/ac pre-boot surface dribble-band UAN
30 lb N/ac post anthesis foliar spray UAN
30 lb N/ac post anthesis surface dribble-band UAN

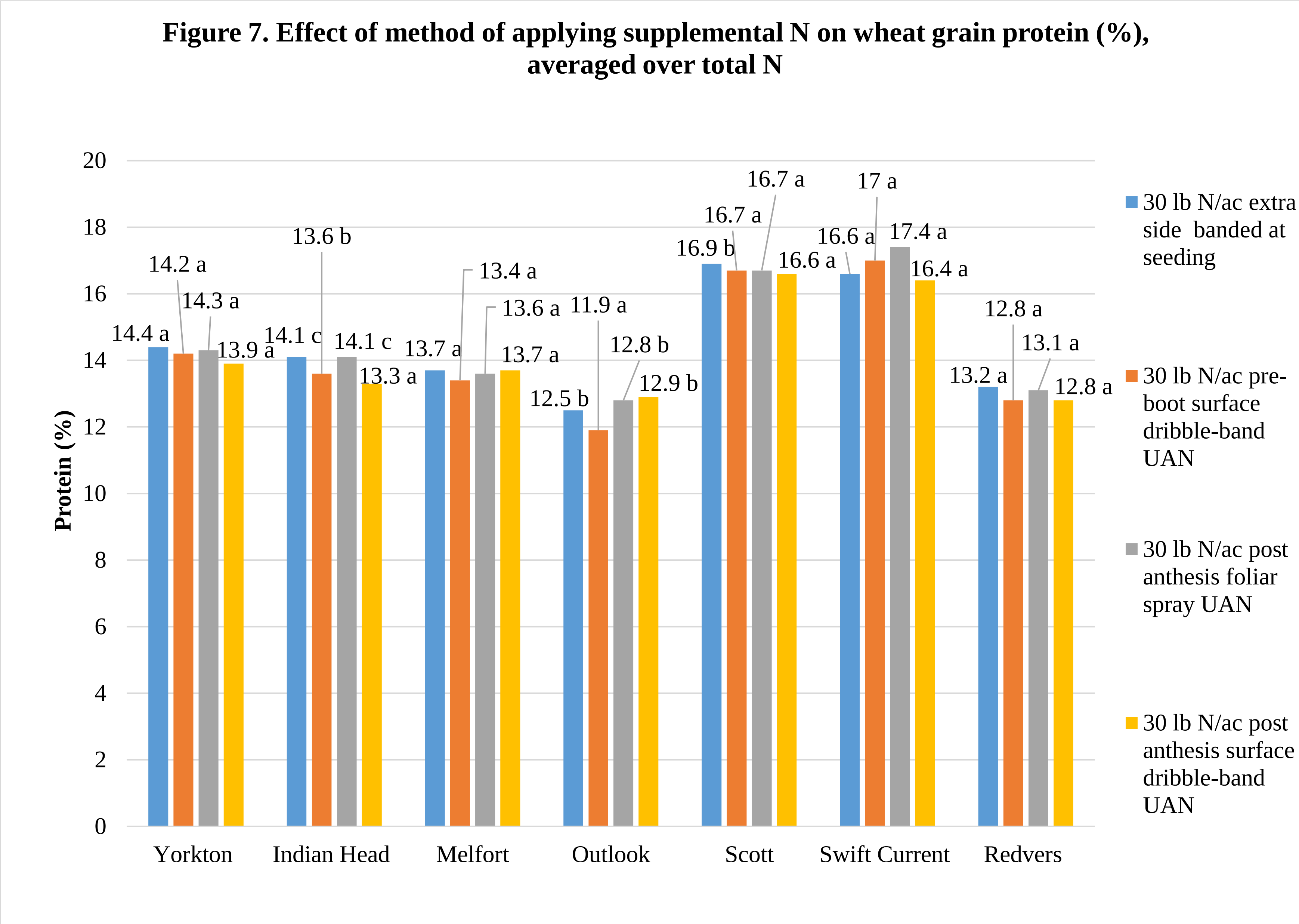


Figure 7. Effect of method of applying supplemental N on wheat grain protein (%), averaged over total N
Protein (%)
20
18
16
14
12
10
8
6
4
2
0
14.4 a
14.2 a
14.3 a
13.9 a
14.1 c
13.6 b
14.1 c
13.3 a
13.7 a
13.4 a
13.6 a
13.7 a
12.5 b
11.9 a
12.8 b
12.9 b
16.9 b
16.7 a
16.7 a
16.6 a
16.6 a
17 a
17.4 a
16.4 a
13.2 a
12.8 a
13.1 a
12.8 a
Yorkton
Indian Head
Melfort
Outlook
Scott
Swift Current
Redvers
30 lb N/ac extra side banded at seeding
30 lb N/ac pre-boot surface dribble-band UAN
30 lb N/ac post anthesis foliar spray UAN
30 lb N/ac post anthesis surface dribble-band UAN

Figure 8. Effect of method of applying supplemental N on wheat grain protein (kg/ha), averaged over total N

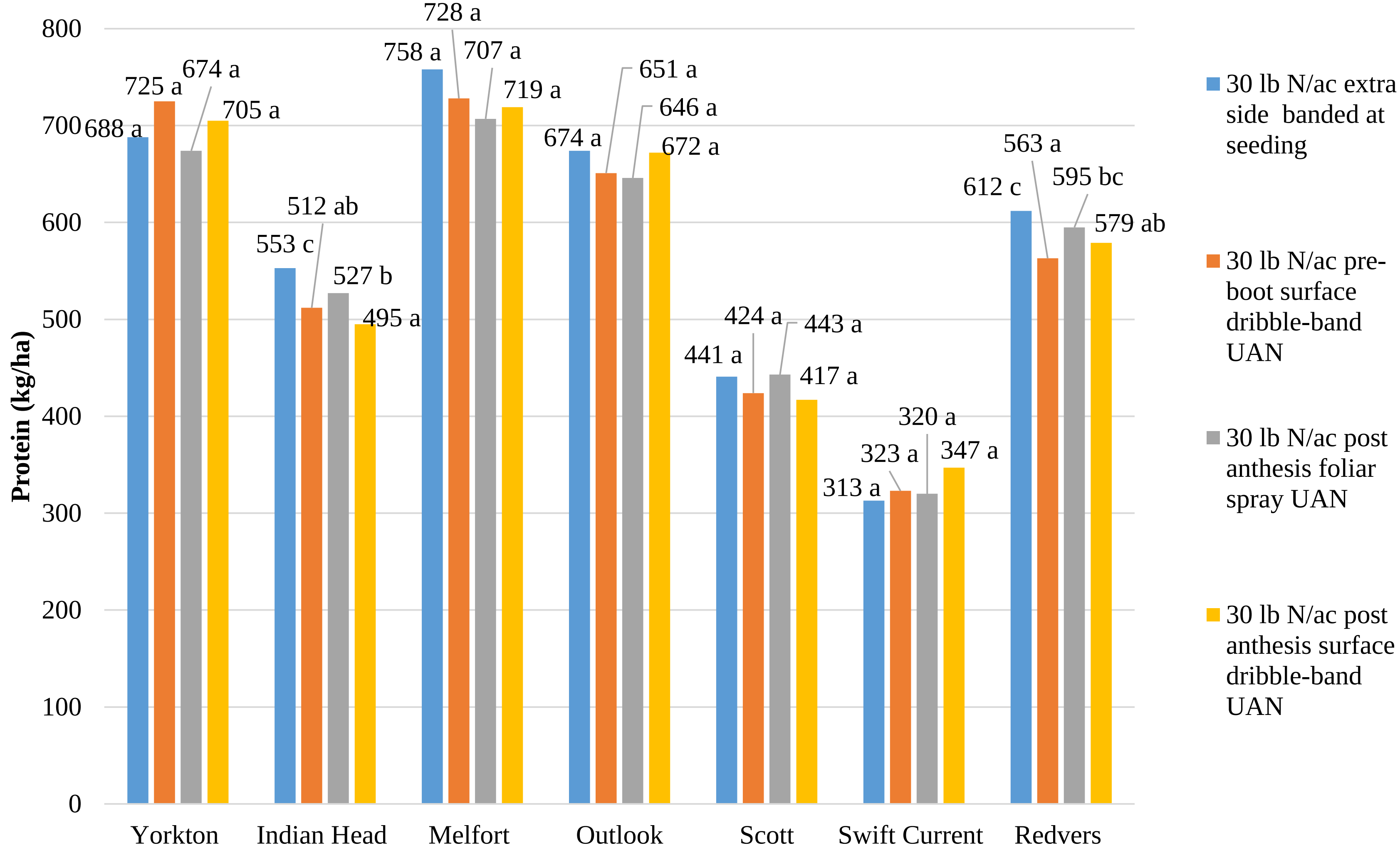


Figure 9. Spread (cents/%/bu) required to cover the cost of 30 lbs N/ac of UAN + $5/ac cost of application.

Protein spread 66 cents/%/bu (February 2018)

Crop Yield (bu/ac)	40	50	60	70
Protein Increase (%)	0.5	0.5	0.5	0.5
$N/lbs				
0.3	70	56	47	40
0.35	78	62	52	44
0.4	85	68	57	49
0.45	93	74	62	53
0.5	100	80	67	57
0.55	108	86	72	61
0.6	115	92	77	66
0.65	123	98	82	70

Crop Yield (bu/ac)	40	50	60	70
Protein Increase (%)	1	1	1	1
$N/lbs				
0.3	35	28	23	20
0.35	39	31	26	22
0.4	43	34	28	24
0.45	46	37	31	26
0.5	50	40	33	29
0.55	54	43	36	31
0.6	58	46	38	33
0.65	61	49	41	35

10. Conclusions and Recommendations

Wheat yield and grain protein increased with added nitrogen in this study. Applying an additional 30 lbs N/ac late in the season to base rates of 70 and 100 lbs N/ac of side-banded urea significantly increased grain protein by 0.8% and 0.6%, respectively when averaged over location and method of application. This supports the hypothesis that split applications provide greater protein increases with more N deficient wheat. However, split applications did not increase wheat yield or protein relative to side-banding all the N at seeding. In terms of nitrogen use efficiency, it was frequently better to place all the nitrogen down at seeding in this study. Nitrogen from split applications was less efficient as it was likely stranded at the soil surface due to dry conditions or lost to volatilization. Late season applications of UAN can also result in leaf burn and potentially even reduce yields. Reduced yield may account for some of the observed increase in protein from late season UAN applications as foliar spray applications with higher levels of leaf burn also had somewhat higher protein; however, there was one site where, at the post-anthesis stage, foliar applied UAN did appear to be more effective for increasing protein than dribble banding. Pre-boot dribble band applications of UAN typically caused the least amount of crop injury. This study concludes that late season nitrogen can be used to increase protein, but doing so was never advantageous over simply side-banding the extra nitrogen at seeding under the conditions encountered. However, if a crop has been under fertilized for its potential, late season supplemental N can provide a protein boost of 0.8%. This will increase net returns, but only when protein spreads are at historical highs. If increasing protein with a late season application of N is desired, every effort should be made to reduce leaf burn. As expected, pre-boot dribble banding UAN was safer on the crop than foliar sprays post anthesis in this study. Spraying should not occur at temperatures above 20ºC. Diluting 50:50 with water may reduce leaf burn with foliar applications but the effects of dilution with dribble-banding are uncertain. For example, dilution also doubles the total solution application volume required and reduces surface tension of the UAN which could result in greater potential for leaf burn in dribble-band applications. With foliar applications the objective is to get as much product as possible retained on the leaves while, dribble-band applications are specifically targeting the soil surface. Recent studies have also shown that melted urea may be safer on the crop than UAN. Care must be taken not to freeze lines when dissolving urea as it is an endothermic reaction. Moreover, only urea low in biuret should be used otherwise severe leaf burning will occur.

11. Supporting Information

Acknowledgements:

This project was funded through the Saskatchewan Wheat Development Commission and Agricultural Demonstration of Practices and Technologies (ADOPT) initiative under the Canada-Saskatchewan Growing Forward 2 bi-lateral agreement. Adopt signs were posted during annual tours.

12. Appendices

Table 4. Significance of main effects and interactions for total N applied and method of applying supplemental N (30 lbs N/ac) on wheat yield at multiple locations in 2018.

	Yield						
	Yorkton	**Indian Head**	**Melfort**	**Outlook**	**Scott**	**Swift Current**	**Redvers**
Effect	------------------------------- p-values ^{z}-------------------------------------						
Total nitrogen (N)	Ns	0.0010	<0.0001	Ns	Ns	Ns	0.0044
Method (M)	Ns	0.0865	0.0159	Ns	Ns	Ns	Ns
N x M	Ns	0.0019	<0.0001	Ns	Ns	Ns	0.0150

^{z} p-values $\leq$ 0.05 indicate that a treatment effect was significant and not due to random variability

Table 5. Main effect means for total nitrogen applied and method of applying supplemental nitrogen (30 lbs N/ac) on wheat yield (kg ha^{-2}) at multiple locations in 2018.

Main effect	**Yield**						
	Yorkton	**Indian Head**	**Melfort**	**Outlook**	**Scott**	**Swift Current**	**Redvers**
Total Nitrogen Applied	---------- kg ha^{-2} ----------						
100 lbs N/ac	4899 a	3685 a	5087 a	5145 a	2580 a	1945 a	4373 a
130 lbs N/ac	4956 a	3888 b	5610 b	5391 a	2588 a	2139 a	4679 b
LSD	Ns	110	156	Ns	Ns	Ns	199
Method of applying supplemental N							
30 lbs N/ac extra side banded at seeding	4819 a	3910 b	5539 b	5394 a	2613 a	1984 a	4639 a
30 lbs N/ac pre-boot surface dribble-band UAN	5109 a	3769 ab	5407 ab	5446 a	2546 a	2008 a	4400 a
30 lbs N/ac post anthesis foliar spray UAN	4698 a	3746 a	5188 a	5052 a	2657 a	1939 a	4554 a
30 lbs N/ac post anthesis surface dribble-band UAN	5082 a	3723 a	5259 a	5180 a	2520 a	2238 a	4512 a
LSD	Ns	156	221	Ns	Ns	Ns	Ns

Table 6. Means for total nitrogen applied by method of applying supplemental nitrogen on wheat yield (Kg ha^{-2}) at multiple locations in 2018.

Main effect	Yield							
	Yorkton	Indian Head	Melfort	Outlook	Scott	Swift Current	Redvers	All Sites Average
	------------------ Kg ha^{-2} ------------------							
1. 70 lbs N/ac side banded as urea at seeding	4788 a	3498 a	4997 a	4730 a	2469 a	2184 a	4070 a	3819 a
2. 100 lbs N/ac side banded as urea at seeding	4678 a	3865 cd	5295 bc	5388 a	2574 a	2065 a	4401 ab	4038 bc
3. 130 lbs N/ac side banded as urea at seeding	4960 a	3955 d	5783 d	5400 a	2652 a	1904 a	4877 c	4219 cd
4. 70 lbs N/ac sided banded as urea at seeding + 30lbs N/ac pre-boot surface dribble-band UAN[1,3]	4860 a	3633 abc	4980 a	5218 a	2565 a	1883 a	4340 ab	3925 ab
5. 100 lbs N/ac side banded as urea at seeding + 30lbs N/ac pre-boot surface dribble-band UAN[1,3]	5359 a	3905 d	5835 d	5673 a	2526 a	2133 a	4461 ab	4270 d
6. 70 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis foliar spray UAN[2,4]	4798 a	3583 ab	4943 a	5097 a	2674 a	1902 a	4423 ab	3917 ab
7. 100 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis foliar spray UAN[2,4]	4598 a	3909 d	5433 bc	5006 a	2641 a	1977 a	4684 abc	4035 bc
8. 70 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis surface dribble-band UAN[2,3]	5260 a	3661 abc	5131 ab	4875 a	2506 a	1932 a	4329 ab	3956 ab
9. 100 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis surface dribble-band UAN[2,3]	4905 a	3785 abcd	5389 bc	5484 a	2533 a	2544 a	4695 abc	4191 cd
L.S.D	Ns	227.0	291.1	Ns	Ns	Ns	400.7	189

Table 7. Significance of main effects and interactions for total N applied and method of applying supplemental N (30 lbs N/ac) on wheat protein at multiple locations in 2018.

	Protein (%)						
	Yorkton	**Indian Head**	**Melfort**	**Outlook**	**Scott**	**Swift Current**	**Redvers**
Effect	----------p-values[z]----------						
Total nitrogen (N)	0.0055	<0.0001	0.0003	<0.0001	<0.0001	Ns	<0.0001
Method (M)	Ns	<0.0001	Ns	0.0014	0.0055	Ns	Ns
N x M	0.0029	<0.0001	0.0002	<0.0001	<0.0001	Ns	Ns

Table 8. Main effect means for total nitrogen applied and method of applying supplemental Nitrogen (30 lbs/ac) on wheat protein (%) at multiple locations in 2018.

Main effect	**Protein**						
	Yorkton	**Indian Head**	**Melfort**	**Outlook**	**Scott**	**Swift Current**	**Redvers**
Total Nitrogen Applied	---------- % ----------						
100 lbs N/ac	13.9 a	13.2 a	13.3 a	11.7 a	16.4 a	16.9 a	12.4 a
130 lbs N/ac	14.5 b	14.4 b	13.9 b	13.4 b	17.0 b	16.8 a	13.5 b
LSD	0.36	0.19	0.32	0.35	0.11	Ns	0.33
Method of applying supplemental N							
30 lbs N/ac extra side banded at seeding	14.4 a	14.1 c	13.7 a	12.5 b	16.9 b	16.6 a	13.2 a
30 lbs N/ac pre-boot surface dribble-band UAN	14.2 a	13.6 b	13.4 a	11.9 a	16.7 a	17.0 a	12.8 a
30 lbs N/ac post anthesis foliar spray UAN	14.3 a	14.1 c	13.6 a	12.8 b	16.7 a	17.4 a	13.1 a
30 lbs N/ac post anthesis surface dribble-band UAN	13.9 a	13.3 a	13.7 a	12.9 b	16.6 a	16.4 a	12.8 a
LSD	Ns	0.28	Ns	0.49	0.16	Ns	Ns

Table 9. Means for total nitrogen applied by method of applying supplemental N on wheat protein (%) at multiple locations in 2018.								
Main effect	**Protein**							
	Yorkton	**Indian Head**	**Melfort**	**Outook**	**Scott**	**Swift Current**	**Redvers**	**All Sites**
	-- % ----------------------------------							
1.-70 lbs N/ac sided banded as urea at seeding	12.9 a	12.3 a	12.3 a	10.4 a	15.8 a	16.4 a	11.6 a	13.1 a
2.-100 lbs N/ac side banded as urea at seeding	14.1 bc	13.7 cd	13.4 bc	11.8 b	16.7 b	16.5 a	12.7 bc	14.1 c
3. 130 lbs N/ac side banded as urea at seeding	14.6 c	14.6 e	14.0 c	13.3 cd	17.1 c	16.7 a	13.7 d	14.8 de
4. 70 lbs N/ac sided banded as urea at seeding + 30lbs N/ac pre-boot surface dribble-band UAN[1,3]	14 bc	13.0 b	13.2 b	11.0 a	16.4 b	16.9 a	12.3 ab	13.8 b
5. 100 lbs N/ac side banded as urea at seeding + 30lbs N/ac pre-boot surface dribble-band UAN[1,3]	14.5 c	14.1 d	13.7 bc	12.8 c	16.9 bc	17.1 a	13.3 cd	14.6 d
6. 70 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis foliar spray UAN[2,4]	14.2 c	13.5 c	13.2 b	12.0 b	16.4 b	17.4 a	12.5 b	14.1 c
7. 100 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis foliar spray UAN[2,4]	14.5 c	14.7 e	14.0 c	13.6 d	17.0 bc	17.5 a	13.7 d	15.0 e
8. 70 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis surface dribble-band UAN[2,3]	13.4 ab	12.4 a	13.3 b	12.0 b	16.3 b	16.9 a	12.2 ab	13.8 b
9. 100 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis surface dribble-band UAN[2,3]	14.4 c	14.1 d	14.0 c	13.9 d	16.9 bc	15.9 a	13.4 cd	14.6 d
L.S.D	0.80	0.39	0.64	0.65	0.26	Ns	0.73	0.27

Table 10. Significance of main effects and interactions for total N applied and method of applying supplemental N (30 lbs N/ac) on flag leaf burn (%) at multiple locations in 2018.

	Flag leaf burn (%)						
	Yorkton	**Indian Head**	**Melfort**	**Outlook**	**Scott**	**Swift Current**	**Redvers**
Effect	---------------------------------- p-values [z] ------------------------------------						
Total nitrogen (N)	Ns	Ns	Ns	Ns	Ns	0.0059	Ns
Method (M)	<0.0001	<0.0001	0.0004	0.0014	<0.0001	<0.0001	<0.0001
N x M	Ns	Ns	Ns	Ns	0.0717	0.0965	Ns

Table 11. Main effect means for total nitrogen applied and method of applying supplemental nitrogen (30 lbs N/ac) on flag leaf burn (%) at multiple locations in 2018.

Main effect	**Flag leaf burn**						
	Yorkton	**Indian Head**	**Melfort**	**Outlook**	**Scott**	**Swift Current**	**Redvers**
Total Nitrogen Applied	-- % -----------------------------------						
100 lbs N/ac	8.5 a	14.4 a	2.9 a	5.6 a	10.8 a	13.4 b	8.8 a
130 lbs N/ac	6.6 a	12.2 a	2.3 a	5.3 a	9.2 a	5.3 a	8.4 a
LSD	Ns	Ns	Ns	Ns	Ns	5.5	Ns
Method of applying supplemental N							
30 lbs N/ac extra side banded at seeding	0 a	0 a	0 a	1.3 a	0 a	0 a	0 a
30 lbs N/ac pre-boot surface dribble-band UAN	0 a	0 a	6.2 c	4.4 a	omitted	1.3 a	0 a
30 lbs N/ac post anthesis foliar spray UAN	23.1 c	28.9 b	0.6 a	12.5 b	6.6 b	26.3 c	28.1 c
30 lbs N/ac post anthesis surface dribble-band UAN	7.1 b	24.3 b	3.5 b	3.8 a	9.8 b	10 b	6.1 b
LSD	4.27	7.7	2.8	5.3	3.4	7.8	2.2

Table 12. Means for total nitrogen applied by timing of supplemental nitrogen on flag leaf burn (%) at multiple locations in 2018.

Main effect	Flag leaf burn						
	Yorkton	Indian Head	Melfort	Outlook	Scott	Swift Current	Redvers
	-- % --------------------------------						
1. 70 lbs N/ac sided banded as urea at seeding	0	0	0	1.3	0	0	0
2. 100 lbs N/ac side banded as urea at seeding	0	0	0	1.3	0	0	0
3. 130 lbs N/ac side banded as urea at seeding	0	0	0	1.3	0	0	0
4. 70 lbs N/ac sided banded as urea at seeding + 30lbs N/ac pre-boot surface dribble-band UAN[1,3]	0	0	6.8	5.0	27.5	2.5	0
5. 100 lbs N/ac side banded as urea at seeding + 30lbs N/ac pre-boot surface dribble-band UAN[1,3]	0	0	5.7	3.8	20.0	0	0
6. 70 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis foliar spray UAN[2,4]	26.3	31.4	1.3	13.8	6.4	32.5	28.8
7. 100 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis foliar spray UAN[2,4]	20	26.5	0	11.3	6.9	20.0	27.5
8. 70 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis surface dribble-band UAN[2,3]	7.8	26.3	3.8	2.5	9.5	18.8	6.3
9. 100 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis surface dribble-band UAN[2,3]	6.5	22.2	3.3	5.0	10.0	1.3	6.0
L.S.D	Ns	Ns	Ns	Ns	4.9	Ns	Ns

Table 13. Significance of main effects and interactions for total N applied and method of applying supplemental N (30 lbs N/ac) on protein (kg/ha) at multiple locations in 2018.

	Protein (kg/ha)						
	Yorkton	**Indian Head**	**Melfort**	**Outlook**	**Scott**	**Swift Current**	**Redvers**
Effect	-------------------------------- p-values [z] --------------------------------------						
Total nitrogen (N)	Ns	<0.0001	<0.0001	<0.0001	Ns	Ns	<0.0001
Method (M)	Ns	<0.0001	Ns	Ns	Ns	Ns	0.0178
N x M	Ns	<0.0001	<0.0001	<0.001	0.0704	Ns	Ns

Table 14. Main effect means for total nitrogen applied and method of applying supplemental nitrogen (30 lbs N/ac) on protein (kg/ha) at multiple locations in 2018.							
Main effect	**Protein**						
	Yorkton	**Indian Head**	**Melfort**	**Outlook**	**Scott**	**Swift Current**	**Redvers**
Total Nitrogen Applied	-- kg/ha -----------------------------------						
100 lbs N/ac	680 a	485 a	675 a	600 a	424 a	312 a	543 a
130 lbs N/ac	717 a	558 b	781 b	721 b	438 a	340 a	631 b
LSD	Ns	12.4	32.7	49.9	Ns	Ns	21.4
Method of applying supplemental N							
30 lbs N/ac extra side banded at seeding	688 a	553 c	758 a	674 a	441 a	313 a	612c
30 lbs N/ac pre-boot surface dribble-band UAN	725 a	512 ab	728 a	651 a	424 a	323 a	563 a
30 lbs N/ac post anthesis foliar spray UAN	674 a	527 b	707 a	646 a	443 a	320 a	595 bc
30 lbs N/ac post anthesis surface dribble-band UAN	705 a	495 a	719 a	672 a	417 a	347 a	579 ab
LSD	Ns	17.5	Ns	Ns	Ns	Ns	30.2

Table 15. Means for total nitrogen applied by method of applying supplemental nitrogen on protein (kg/ha) at multiple locations in 2018.

Main effect	Protein							
	Yorkton	**Indian Head**	**Melfort**	**Outook**	**Scott**	**Swift Current**	**Redvers**	**All Sites Average**
	---------- kg/ha ----------							
1. 70 lbs N/ac sided banded as urea at seeding	614 a	429 a	614 a	492 a	390 a	341 a	471 a	479 a
2. 100 lbs N/ac side banded as urea at seeding	656 a	530 d	707 bc	633 bcd	429 a	324 a	559 bc	548 c
3. 130 lbs N/ac side banded as urea at seeding	721 a	575 e	808 d	715 de	453 a	302 a	665 e	606 d
4. 70 lbs N/ac sided banded as urea at seeding + 30lbs N/ac pre-boot surface dribble-band UAN[1,3]	678 a	473 bc	656 ab	574 ab	421 a	302 a	531 b	519 b
5. 100 lbs N/ac side banded as urea at seeding + 30lbs N/ac pre-boot surface dribble-band UAN[1,3]	773 a	550 de	799 d	727 de	426 a	344 a	594 cd	602 d
6. 70 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis foliar spray UAN[2,4]	682 a	482 c	651 ab	609 bc	437 a	311 a	550 b	532 b
7. 100 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis foliar spray UAN[2,4]	666 a	572 e	763 cd	682 cde	448 a	329 a	639 e	586 d
8. 70 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis surface dribble-band UAN[2,3]	703 a	455 b	684 b	584 ab	408 a	309 a	530 b	525 b
9. 100 lbs N/ac side banded as urea at seeding + 30 lbs/ac N post-anthesis surface dribble-band UAN[2,3]	707 a	535 d	753 cd	761 e	426 a	385 a	628 de	599 d
L.S.D	Ns	24.7	61.7	96.0	Ns	Ns	40.4	28.8

13. Abstract

Abstract/Summary:

A study was conducted at seven locations across Saskatchewan to determine if wheat yield and/or protein could be increased by applying 30 lbs N/ac of UAN at pre-boot or post-anthesis. UAN was subsequently applied in addition to base rates of 70 or 100 lbs N/ac of side-banded urea. The in-crop N was either dribble banded pre-boot or post-anthesis or foliar sprayed post-anthesis. Leaf burning was most severe with the foliar spray application and dribble banding pre-boot resulted in the least amount of crop damage. On average, the supplemental application of 30 lbs N/ac increased grain protein by 0.8 and 0.6% when applied to base rates of 70 and 100 lbs N/ac, respectively. This supports the hypothesis that supplemental N can increase grain protein more when N deficiency is greater. While applying supplemental N increased protein it did not increase either yield or protein compared to side banding that additional 30 lbs N/ac at seeding, in some instances split applications resulted in less yield and/or protein. In this study, nitrogen use efficiency was better when all the nitrogen was side-banded at seeding. However, if a crop has been fertilized below its potential, a late season application of 30 lbs N/ac can increase protein by 0.8%; this protein increase alone will only prove to be economical when the protein spreads are at historical highs, therefore the need for N should be identified early enough that yield can also be increased..