2020 Research Report

from the

East Central Research Foundation

Project Title: Increasing Wheat Protein with Post Emergent Applications of UAN vs Dissolved Urea

(SDWC # 132-190325)

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Project Identification

1. **Project Number:** 132-190325
2. **Producer Group Sponsoring the Project:** SaskWheat
3. **Project Location(s):** Yorkton, Prince Albert, Indian Head, Melfort, Redvers, Outlook, Scott and Swift Current, SK
4. **Project start and end dates (month & year):** April 2019 to March 2021
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Objectives and Rationale

6. **Project objectives:**

The overall objective of this project was to demonstrate the potential of an additional 30 lb N/ac applied late season to increase either wheat yield or grain protein compared to applying all nitrogen (N) at seeding. The impact of nitrogen source, crop staging and application method were compared.

Specifically, the intent was to demonstrate the following concepts:

a. Dribble banded applications of UAN cause less flag leaf burn than broadcast foliar sprays applied post-anthesis.
b. Dribble banding UAN at the earlier boot stage causes less flag leaf burn than when applied post-anthesis.
c. Diluting dribble band applications of UAN is not necessary and may actually increase flag leaf burn.
d. Strategies resulting in less flag leaf burn will produce a better yield/protein response (ie: more protein/ac).

7. Project Rationale:

Recently, producers have been disappointed by low levels of grain protein. When regional protein levels are low, the premiums offered for high protein wheat tend to increase. This has left producers wondering what can be done to increase protein levels in the future. Many studies, dating back to the 1990s, have shown post-emergent applications of nitrogen can increase grain protein when made at late vegetative stages. Guy Lafond assessed the feasibility of applying foliar N at both the boot stage and post-anthesis for spring and winter wheat [1]. He determined that this practice had merit, but the results could vary depending on initial N supply and weather conditions. However, dribble banding at the earlier boot stage increased grain protein more consistently and reduced the potential for flag leaf burn. UAN (28-0-0) produces large drops that do not disperse on the leaf surface because they have a high surface tension and tend to roll off. Dilution may reduce surface tension and actually increase leaf burn [2], or increased leaf burn may just be a function of a higher volume applied.

Western Canadian research has found little reason to support the use of broadcast foliar sprays over dribble banding. Broadcast foliar sprays cause more leaf burn, and since little nitrogen is actually absorbed through the leaves, there is little benefit to the practice. The University of Manitoba found the recovery of foliar applied 15N labelled urea (in solution) was only 4-27% compared to 32-70% with soil application. Under field conditions with foliar UAN, most of the uptake occurs after rainfall events wash the N into the soil, where it is taken up through the roots [3].

Despite these results, broadcast foliar sprays post-anthesis are popular in the northern United States and are practiced in Manitoba. The general recommendation is to dilute UAN 50:50 with water and spray when conditions are cool to reduce leaf burning. While foliar applications of UAN post-anthesis frequently increase protein, this practice does not always prove to be economical. Research lead by John Heard with Manitoba Agriculture evaluated the benefit of post-anthesis UAN on 15 farm sites from 2015 to 2016 [4]. The impact on protein was largely positive and statistically significant 60% of the time. On average, protein of CNHR varieties was increased 0.6% when an additional 30 lb N/ac was applied post-anthesis. However, post-anthesis UAN only proved to be economical at 2 of 15 sites, and premiums for higher protein concentrations are not guaranteed.

Broadcast foliar sprays with dissolved urea, instead of UAN may prove to be more beneficial.

Amy Mangin with the University of Manitoba recently found broadcast foliar sprays of dissolved urea sprayed post-anthesis not only resulted in less leaf burn but also produced greater yields and higher grain protein compared to UAN [5]. Dissolved urea is a standard product used for foliar applications in the UK and is considered to be safer on the crop than UAN. While both UAN and dissolved urea were applied at 30 lb N/ac in Mangin's study, the % N concentration of the solutions differed between the products. The UAN solution was 14%, whereas the urea solution was only 9%. This may have also contributed to the greater crop safety observed with dissolved urea. In our demonstration, the intent was to compare UAN and dissolved urea at 14% N to provide a fair comparison. However, this did not occur, and the logic for this comparison is flawed. Later in the paper this will be discussed in full.

Producers can create their own solution of urea on farm; however, care must be taken as dissolving urea is extremely endothermic and can freeze lines. Urea should be dissolved slowly into warm water and not into cold water pulled from a well. In addition, producers should only dissolve urea with less than 1% biuret. Biuret is a by-product that can cause severe leaf burning, but it is normally not a concern with urea manufactured in North American.

[1] Lafond, G and J. McKell. 1998. The Effects of Foliar Applied Nitrogen on Grain Protein Concentration in Spring and Winter Wheat. Proceedings of the Wheat Protein Symposium 298-304

[2] Stu Brandt personal communication

[3] Rawluk, C. D. L., Racz, G. J. and Grant, C. A. 2000. Uptake of foliar or soil application of 15N-labelled urea solution at anthesis and its affect on wheat grain yield and protein. Can. J. Plant Sci. 80: 331–334.

[4] Heard, J., Sabourin, B., Faroq, A. and L. Kaminski. On-farm-tests evaluate nitrogen rate, source and timing for spring wheat yield and protein. Poster.

[5] http://umanitoba.ca/faculties/afs/agronomists_conf/media/7__1_30_PM_DEC_14_MANGIN_MAC_2017_NOV23.pdf

Methodology and Results

8. Methodology:

In 2019 and 2020 trial sites were initiated near Swift Current (dry Brown), Outlook (Brown), Scott (Dark Brown), Indian Head (thin Black), Yorkton (Black), Melfort (moist Black), Prince Albert (Grey) and Redvers (Dark Brown). Treatments were designed to compare boot stage and post-anthesis timings of split N relative to side-banding all the N at seeding. Dribble band and broadcast applications of UAN and dissolved urea were compared. All split applications of N were supposed to be 30 lb N/ac applied to a base rate of 70 lb N/ac. While late season applications of UAN and diluted UAN were applied at the targeted 30 lb N/ac, dissolved urea treatments (trts 7 and 9) were only applied at 25 lb N/ac due to a calculation error more fully described in the appendix. Other macronutrients were applied at each site to be non-limiting to yield.

Treatments (Table 1) were arranged in a Randomized Complete Block Design (RCBD) with 4 replicates at each site. Plot size, row spacing, and fertilizer application techniques at seeding varied between locations depending on equipment. Tables 2 and 3 describe how the trials were maintained and provides the dates of key operations. All trials were seeded in good time, with dates ranging from May 8 to 24 in 2019 and from May 7 to 28 in 2020. Fungicide for leaf disease or leaf disease plus fusarium head blight were applied at all site years except Melfort and Scott in 2019 and Outlook and Swift Current in 2020. The vast majority of sites were harvested in August and September in good condition. Grain yield was cleaned and corrected to a uniform moisture of 14.5%. Precipitation and temperatures for each location were compiled from the nearest Environment Canada weather station (Tables 4 and 5). To aid with the interpretation of results, composite soil samples were collected from each location and the results are presented in Table 6.

Table 1. Treatment List for the Increasing Wheat Protein with Post Emergent Applications of UAN vs Dissolved Urea Trial

Treatment #	**Seeding**	**Post emergence application**				
	Lb N/ac of Side- banded Urea	N (lb/ac)	Product	%N	method	Stage
1	70	na	Na	na	na	na
2	100	na	Na	na	na	na
3	70	30	UAN	15.7	dribble[1]	boot
4	70	30	UAN	28	dribble[2]	boot
5	70	30	UAN	15.7	dribble[1]	Post-anthesis
6	70	30	UAN	28	dribble[2]	Post-anthesis
7	70	25	Urea Sol'n	14	Dribble [3]	Post-anthesis
8	70	30	UAN	15.7	Broadcast[4]	Post-anthesis
9	70	25	Urea Sol'n	14	Broadcast[5]	Post-anthesis

[1] Sprayed with dribble band nozzle at 20 US gal/ac to deliver 30 lb N/ac (10 gal/ac UAN + 10 gal/ac water = 15.7% N solution by weight)
[2] Sprayed with dribble band nozzle at 10 US gal/ac to deliver 30 lb N/ac (undiluted UAN =28% N solution by weight)
[3] Sprayed with dribble band nozzle at 20 gal/ac to deliver 25 lb N/ac (1.66 Kg of urea dissolved in 1 US gallon of water = 14% N solution)
[4] Sprayed with 02 flat fan nozzles at 20 gal/ac to deliver 30 lb N/ac (10 gal/ac UAN + 10 gal/ac water = 15.7% N solution by weight)
[5] Spray with 02 flat fan nozzles at 20 gal/ac to deliver 25 lb N/ac (1.66 Kg of urea dissolved in 1 US gallon of water = 14% N solution)

Table 2. Dates of operations in 2020 for each participating location

Activity	Indian Head	Melfort	Outlook	Prince Albert	Redvers	Scott	Swift Current	Yorkton
	---------------------------Date----------------------------							
Pre-seed Herbicide Application	May 14 (Roundup Transorb)	May 24 (Heat LQ + Glyphosate 540)	May 19 (Cleanstart + AIM)	N/A	May 14 (Glyphosate)	May 9 (Glyphosate 540 + AIM)	May 4 (Glyphosate + AIM)	N/A
Seeding	May 12	May 23	May 28	May 25	May 8	May 14	May 16	May 7
Emergence Counts	June 4	June 16	June 9	June 15	May 26	June 11	June 4	May 26
In-crop Herbicide Application	June 15 (Octain + Simplicity)	June 23 (Prestige XC) & July 3 (Axial)	June 9 (Infinity) & June 10 (Simplicity)	June 10 (Infinity)	June 2 (Infinity FX)	June 15 (Axial Ipak)	May 29 (Liquid Achieve + Buctril M +Turbocharge ADJ)	June 2 (Prestige) June 8 (Simplicity)
Boot N application	June 30	July 16	July 13	July 10	June 29	July 6	June 22	June 22
Post-anthesis N application	July 16	Aug 13	July 29	July 27	July 10	July 27	July 23	July 13
Flag leaf burn Rating	July 20	Aug 20	July 31	Aug 6	July 16		July 30	July 20
In-crop Fungicide Application	July 11 (Prosaro XTR)	July 24 (Caramba)	N/A	July 21 (Twinline)	June 7 (Caramba)	July 16 (Caramba)	N/A	July 2 (Caramba)
Lodging Rating	Aug 13	Sept 16	N/A	Sept 21	N/A	N/A	Aug 25	N/A
Desiccant	Aug 19 (Roundup Transorb)	N/A	N/A	N/A	N/A	Aug 25 (Glyphosate 540)	N/A	(Roundup Transorb)
Harvest	Aug 26	Sept 16	Sept 16	Sept 23	Aug 20	Sept 11	Aug 26	Aug 11

Table 3. Dates of operations in 2019 for each participating location

	----------------------------Date----------------------------							
Activity	**Indian Head**	**Melfort**	**Outlook**	**Prince Albert**	**Redvers**	**Scott**	**Swift Current**	**Yorkton**
Pre-seed Herbicide Application	May 12 (Roundup Weathermax 540)	May 24 (Glyphosate + Heat)	N/A	N/A	N/A	May (Glyphosate 540 + AIM)	May 7 (Glyphosate)	N/A
Seeding	May 14	May 24	May 15	May 23	May 7	May 14	May 8	May 13
Emergence Counts	June 3	June 26	N/a	June 13	June 5	June 11	June 17	June 12
In-crop Herbicide Application	June 17 (OcTTain XL + Simplicity GoDRI)	June 27 (Axial) July 4 Prestige XC	June 10 (Badge II + Simplicity)	June 19 (Axel Extreme, MCPA, Kinetic Copron)	June 10 (Clodinafop + Buctril M)	June 26 (Axial + Buctril M)	June 14 (Varro + OcTTain XL + Agral90)	June 12 (Simplicity + Prestige) June 25 (MCPA) July 3 (MCPA)
Boot N application	July 3	July 16	July 6	July 9	July 3	July 4	July 3	July 3
Post-anthesis N application	July 20	Aug 8	July 19	July 26	July 20	July 23	July 29	July 19
Flag leaf burn Rating	July 25	Aug 16	July 22	July 19 and July 29	N/A	July 11, 18, 30 & Aug 5	N/A	July 25
In-crop Fungicide Application	July 11 (Prosaro)	N/A	July 18 (Caramba)	June 19 (Pivot 418EC)	July 12 (Caramba)	N/A	July 10 (Acapella)	July 11 (Caramba) July 14 (Caramba)
Lodging Rating	Aug 9	N/A	N/A	Sept 23	Sept 7	N/A	Aug 19	Sept 3
Desiccant	Aug 28 (Roundup Weathermax 540)	N/A	N/A	Sept 5 (Glyphosate)	N/A	Sept 6 (Heat LQ + Roundup 540 + Merge)	N/A	Sept 3 (Roundup Transorb)
Harvest	Sept 6	Oct 6	Sept 24	Sept 23	Sept 7	Sept 22	Aug 21	Sept 16

9. Results:

Growing Season Weather

Mean monthly temperatures and precipitation amounts for 2019 and 2020 with long term (1981-2010) averages for 8 sites are listed in Tables 4 and 5. In Yorkton, 2020 was unusually dry in early spring, which greatly reduced yields by about 60% from normal. The rest of the site years had more normal yields.

Table 4. Mean monthly temperatures amounts along with long-term (1981-2010) normals for the 2019 and 2020 growing seasons at 8 sites in Saskatchewan.

Location	Year	May	June	July	August	Avg. / Total
		----------------------------*Mean Temperature (°C)* -------------------				
Indian Head	2020	10.7	15.6	18.4	17.9	15.6
	2019	8.9	15.7	17.4	15.8	14.4
	Long-term	***10.8***	***15.8***	***18.2***	***17.4***	***15.6***
Melfort	2020	10.1	14.3	18.8	17.6	15.2
	2019	8.8	15.3	16.9	14.9	14.0
	Long-term	***10.7***	***15.9***	***17.5***	***16.8***	***15.2***
Outlook	2020	11.3	15.9	19.1	18.8	65.1
	2019	9.9	16.0	18.0	16.2	15.0
	Long-term	***11.5***	***16.1***	***18.9***	***18.0***	***16.1***
Prince Albert	2020	9.2	13.4	17.6	16.1	***14.1***
	2019	9.5	15.8	17.4	15.1	14.5
	Long-term	**11.8**	**16.1**	**18.5**	**17.3**	***14.5***
Redvers	2020	10.5	16.8	19.2	18.5	16.3
	2019	9.5	16.3	18.5	16.6	15.2
	Long-term	***12***	***16***	***19***	***18***	***16.3***
Scott	2020	10.2	14.6	17.1	16	14.5
	2019	*9.1*	*14.9*	*16.1*	*14.4*	*13.6*
	Long-term	***10.8***	***14.8***	***17.3***	***16.3***	***14.8***
Swift Current	2020	*10.9*	*16.6*	*18.2*	*19.5*	*16.3*
	2019	*9.5*	*15.8*	*17.7*	*16.8*	*15.0*
	Long-term	***11***	***15.7***	***18.4***	***17.9***	***15.8***
Yorkton	2020	10.5	16.4	19.9	18.3	16.3
	2019	8.6	16	18.3	16.1	14.8
	Long-term	***10.4***	***15.5***	***17.9***	***17.1***	***15.2***

Table 5. Precipitation amounts along with long-term (1981-2010) normals for the 2019 and 2020 growing seasons at 8 sites in Saskatchewan.

Location	**Year**	**May**	**June**	**July**	**August**	**Avg. / Total**
		-------------------------------- *Precipitation (mm)* ---------------------				
Indian Head	2020	27.3	23.5	37.7	24.9	113.4
	2019	13.3	50.4	53.1	96.0	212.8
	Long-term	***51.7***	***77.4***	***63.8***	***51.2***	***241.4***
Melfort	2020	26.7	103.7	52.4	18.	201.3
	2019	18.8	87.4	72.7	30.7	209.6
	Long-term	***42.9***	***54.3***	***76.7***	***52.4***	***226.3***
Outlook	2020	27.8	79.2	29.6	19.0	155.6
	2019	13.2	90.2	43.8	39.6	186.8
	Long-term	***42.6***	***63.9***	***56.1***	***42.8***	***205.4***
Prince Albert	2020	68.4	91.4	32.2	33.2	225.2
	2019	30.0	54.4	57.4	16.8	158.6
	Long-term	**36.4**	**80.6**	**96.1**	**48.0**	***261.1***
Redvers	2020	68.4	91.4	32.2	33.2	225.2
	2019	18.0	79.0	54.0	88	239
	Long-term	***60***	***91***	***78***	***64***	***293***
Scott	2020	48.3	70.2	129.4	25.8	273.7
	2019	12.7	97.7	107.8	18	236.2
	Long-term	***38.9***	***69.7***	***69.4***	***48.7***	***226.7***
Swift Current	2020	36.3	80.0	62.5	6.5	185.3
	2019	13.3	156	11.1	42.6	223
	Long-term	***42.1***	***66.1***	***44***	***35.4***	***187.6***
Yorkton	2020	16.7	33.6	80.1	49.3	179.7
	2019	11.1	81.6	49.1	32.2	174
	Long-term	***51***	***80***	***78***	***62***	***272***

Soil test Nitrate levels for each location are presented in Table 6. Two sites, testing extremely high in background soil N, were Prince Albert in 2020 and Swift Current in 2019. The rest of the site years had more typical background levels of soil N for continuous cropping systems.

Table 6. Soil Test Nitrate Levels for each location (lb N/ac) in 2019 and 2020.

Nitrate Levels (lbs NO_3-N/ac)	**Indian Head**	**Melfort**	**Outlook**	**Prince Albert**	**Redvers**	**Scott**	**Swift Current**	**Yorkton**
2020								
0-15cm (0-6in)	8	19	4	45 (0-6”)	22	17	23	27
15-30cm (6-12in)		25	4	40 (6-17”)				
15-60cm (6-24in)	15				39	12	27	33
Total 0-60cm (0-24in)	23	66[1]	16	127[1]	61	35	50	60
Total 0-30cm (0-12in)		44		85 (0-17”)				
2019								
0-15cm (0-6in)	16	18	6	15	29	14	42	14
15-30cm (6-12in)				10				
15-60cm (6-24in)	33	17	9		42	18	186	18
Total 0-60cm (0-24in)	49	35	15	37.5[1]	71	32	228	32
Total 0-30cm (0-12in)				25				

[1]Estimation (**Total** 0-30cm (0-12inch) lb N/ac value *1.5)

Table 7 shows temperature at the time of boot stage and post-anthesis applications. It is generally recommended to spray at temperatures below 20^{o}C for broadcast sprays of UAN to reduce the potential for leaf burn. At the boot stage application, only 7 out of 16 site/years were sprayed below 20^{o}C. However, this temperature limit is likely of less concern for dribble band applications, particularly at the boot stage. For the post-anthesis timing, 13 of the 16 site/years started spraying at temperatures below 20^{o}C. The date of significant rainfall after application is also indicated in table 7. Significant rainfall of 10 mm or greater occurred within two weeks after most applications and are indicated in green (Table 7). However, observing or not observing a significant rainfall event was not always a good predictor of protein response.

Table 7. Date of Post-Emergent Nitrogen Application, Temperature and Amount of Rain after Post-Emergent Nitrogen Application in 2019 and 2020.

	Date of Application		Temperature During Application		Next Significant Rainfall after Post-emergent N Application (>10mm)	
	Boot	Post-Anthesis	Boot	Post-Anthesis	Boot	Post-Anthesis
2020						
Indian Head	June 30	July 16	22-25 C	20-22C	None	None
Melfort	July 16	Aug 13	20 C	12C	None	None
Outlook	July 13	July 29	17 C	18.5C	July 18 (12.5mm)	Aug 1 (12.5mm)
Prince Albert	July 10	July 27	18 C	13C	Aug 3 (13mm)	Aug 3 (13mm)
Redvers	June 29	July 10	23 C	15 C	June 30 (15mm)	None
Scott	July 6	July 27	24 C	19.5-22.7C	July 8 (68mm)	Aug 27 (17mm)
Swift Current	June 22	July 23	20 C	21C	June 29 (16.7mm)	None
Yorkton	June 22	July 13	20C	18-19C	July 13 (17 mm)	July 20 (29mm)
2019						
Indian Head	July 3	July 20	18-20ºC	17-18ºC	July 13 – 17 (30mm)	Aug 9- 12 (61mm)
Melfort	July 16	Aug 8	20.9ºC	19-20ºC	July 17-18 (29.3mm)	Aug 22-23 (15mm)
Outlook	July 6	July 19	16.3ºC	15.5ºC	July 14-16 (22.4mm) + Irrigation July 9 and 11 (20.5mm)	Aug 22 (22.8mm) + Irrigation Aug 1 (12.5mm)
Prince Albert	July 9	July 26	19ºC	22ºC	July 17-19 (24.3 mm)	Sept 2 (16.2 mm)
Redvers	July 3	July 20	18-20 ºC	19-21ºC	July 9 (21.3mm)	Aug 12 (20.3mm)
Scott	July 4	July 23	17.9ºC	15.7ºC	July 11-12 (12mm) & July 19-20 (28.7mm)	Aug 7-8 (31.6mm)
Swift Current	July 3	July 29	18ºC	18-22ºC	Aug 11-12 (35.4mm)	Aug 11-12 (35.4mm)
Yorkton	July 3	July 19	20ºC	14ºC	July 6 (20.7mm)	Aug 25-27 (20.2mm)

Significant rainfall events of 10 mm or greater occurring within two weeks of application is printed in green

At Redvers in 2019 and Scott in 2020, crop emergence was a little low at 160 and 163.5 plants/m^2, respectively (Table 8). Emergence was a little high at 393 plants/m^2 for Swift Current in 2019. However, the rest of the site/years had decent to excellent emergence. Lodging was not an issue for any of the site/years (data not shown).

Table 8. Average Crop Emergence for all sites in 2019 and 2020		
	Emergence	
	----------------------------------Plants/m^2--------------------------	
Site	**2020**	**2019**
ECRF-Yorkton	291.3	254.5
SERF-Redvers	203.2	160.0
IHARF-Indian Head	252.0	214.7
WCA-Swift Current	321.6	393.0
WARC-Scott	163.5	232.0
ICDC-Outlook	191.7	N/A
CLC-Prince Albert	263.8	236.1
NARF-Melfort	221.6	186.9

Figure 1 shows the average flag leaf burn ratings for treatments 3 to 9 averaged over 10 site/years. Flag leaf burn data from Scott in 2019-2020, Swift Current in 2019-2020, Melfort in 2019 and Yorkton in 2020 were omitted from this combined analysis for a variety of reasons including the use of a different rating system at Scott and no blind ratings for treatments 3-4 at the other sites (refer to note 1 in appendix for further explanation). However, flag leaf burn ratings were recorded at all sites and the individual site/year data are in Tables 10 and 11 of the appendix.

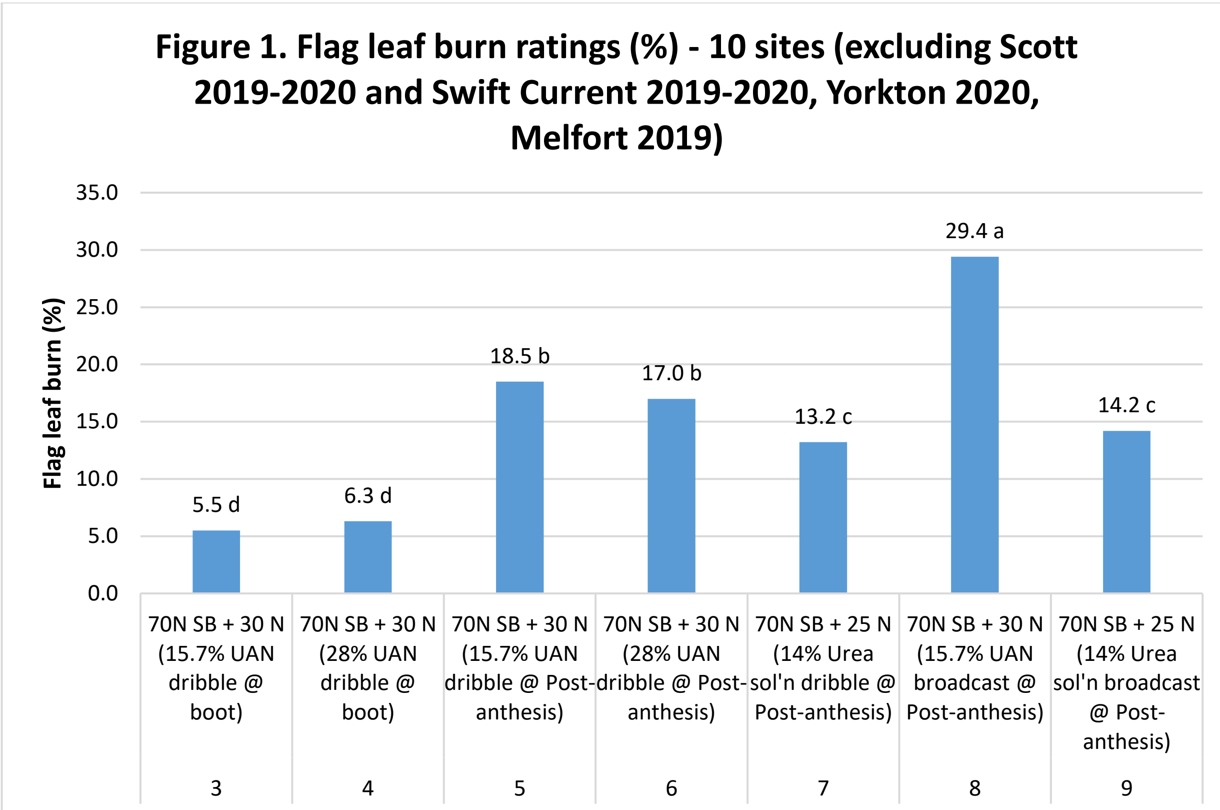
From the combined analysis, all post-anthesis applications of UAN and dissolved urea (trts 5-9), whether dribble banded or broadcast sprayed, significantly increased flag leaf burn relative to dribble banded UAN (15.7 or 28% N) at the boot stage (trts 3-4) (Figure 1). This supports past study by Guy Lafond who also observed less flag leaf burn from boot stage applications of UAN compared to applications made post-anthesis.

Post-anthesis applications of nitrogen caused the most flag leaf burn when UAN (15.7% N) was broadcast sprayed (trt 8) compared to dribble banded. Broadcast spraying caused more leaf burn due to greater foliar coverage compared to dribbling banding. Diluting UAN from 28% to 15.7% N had no effect on flag leaf burn when dribble banding (trt 8 vs 5 and 6) (Figure 1). In other words, diluting UAN was not necessary to further reduce flag leaf burn from dribble banded applications. Unlike UAN, dribble banding dissolved urea did not reduce flag leaf burn relative to broadcast spraying (trt 7 vs 9). However, the level of flag leaf burn resulting from broadcast applications of dissolved urea was already much lower compared to broadcast UAN, leaving relatively less potential to further improve crop safety by dribble banding. While less leaf burn with dissolved urea in this study is supported by past research, it should be noted that the dissolved urea was only applied at 25 lb N/ac and not 30 lb N/ac to match UAN applications as intended. This was due to a calculation error described in Note 2 of the appendix.

There was a significant site/year by treatment interaction (p<0.00001) for the flag leaf burn data (Table 9), meaning not all sites within the combined data reported the same relative treatment effects. While the vast majority of sites rated flag leaf burn to be lower for boot stage applications, differences between post-anthesis applications were less consistent. An exception to the general trend between post-anthesis applications occurred at Outlook in 2019. Dribble banded dissolved urea caused significantly more leaf burn than dribble banded UAN instead of less (Tables 10 and 11 in the appendix). However, this occurrence was likely an anomaly, because in the same year and at the same site (Outlook, 2019), broadcast sprayed dissolved urea caused significantly less leaf burn than broadcast sprayed UAN. While there was variability between sites, the overall trend was for more flag leaf burn with foliar broadcast sprays and for less damage with dissolved urea.

Table 9. Significance of F-values

	10 sites	All 16 site/years		Top 8 yielding site/years		Bottom 8 yielding site/years	
	Flag burn	Yield	Protein	Yield	Protein	Yield	Protein
Site/year (S)	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Treatment (T)	<0.00001	<0.00001	<0.00001	0.0017	<0.00001	0.013	<0.00001
S by T	<0.00001	0.38	<0.00001	0.33	<0.00001	0.37	<0.00001



While there was no significant site/year by treatment interaction for the yield data, there was for the grain protein data (Table 9). Treatments receiving the best combination of yield and grain protein did differ somewhat between locations (Tables 12-15 in appendix), and these differences will be discussed. However, the data will first be discussed averaged over site/year as combining the data smooths out variations and provides results that make the most intuitive sense.

When averaged across all 16 site/years, a number of trends emerged. Sites were responsive to added N. Increasing the rate of side-banded urea from 70 to 100 lb N/ac significantly increased yield from 4261 to 4476 kg/ha (63.4 to 66.6 bu/ac) and significantly increased grain protein from 13.3 to 13.8%, respectively (Figure 2). Split applications of N (trts 5-9) resulted in higher grain protein, but lower yield compared to just side-banding all the N at seeding (trt 2). Post anthesis split N applications showed much larger increases in grain protein and decreases in yield than boot stage split N applications. For example, dribble banding UAN (28% N) post-anthesis at 30 lb N/ac to a base rate of 70 lb N/ac (trt 6) significantly increased grain protein by 0.32% but significantly decreased yield by 322 kg/ha (4.8 bu/ac), compared to the side-banded check of 100 lb N/ac (trt 2). In contrast, dribble banding UAN (28% N) earlier at the boot stage (trt 4), resulted in a more modest grain protein increase of 0.15% but with a relatively lower yield loss of only 55 kg/ha (0.8 bu/ac). The grain yield and protein differences between boot stage and post-anthesis applications may be related to differences in flag leaf burn. Dribble banding UAN post-anthesis caused more flag leaf damage than to the boot stage timing (Figure 1), which may have reduced yield and in turn, increased grain protein (Figure 2). However, it is also possible that more of the N from the boot stage application favored yield over protein because it was earlier than the post-anthesis application. Overall, using dissolved urea post-anthesis tended to result in smaller grain protein increases (0.1%) than UAN. This was likely the result of applying a little less N with dissolved urea (ie: 25 vs 30 lb N/ac).

Producers are more likely to try and increase grain protein with split applications of N when the yield potential of their crop is high and grain protein level is low. To test the benefit of this approach, the trial data was divided into the top 8 and bottom 8 yielding site/years and was then analyzed again separately. The top 8 yielding site/years combined were Prince Albert 2020, Indian Head 2020, Melfort 2019-2020, Scott 2020, Outlook 2019, Redvers 2019 and Yorkton 2019 (Figure 3). The bottom 8 yielding site/years combined were Yorkton 2020, Outlook 2020, Redvers 2020, Swift Current 2019-2020, Prince Albert 2019, Indian Head 2019 and Scott 2019 (Figure 4). While background soil N did differ substantially between site/years, average levels were relatively similar between the top and bottom 8 site/years at 50.5 lb N/ac and 61 lb N/ac in the top 24 inches of soil, respectively (Table 6).

On average, the top yielding site/years produced 5242 kg/ha (78 bu/ac) of wheat at 12.9% grain protein (Figure 3) and the bottom yielding site/years produced 3399 kg/ha (51 bu/ac) of wheat at 14.6% grain protein (Figure 4). The higher level of protein with the lower yielding sites makes sense as environmental conditions that reduce yield potential (ie: moisture stress) tend to result in elevated grain protein. This is one reason why producers are generally less interested in increasing grain protein when the yield potential of their crop looks to be below average.

The general yield and protein response to treatment between the top and bottom site/years was remarkably similar (Figures 3 and 4) and followed a similar pattern to the combined data (Figure 2). Increasing the rate of side-banded N from 70 to 100 lb/ac increased yield and grain protein by 178 kg/ha and 0.4% for the top sites and by 253 kg/ha and 0.5% for the bottom sites, respectively. For top and bottom yielding sites, split applications of N tended to increase grain protein but also reduced yield compared to applying all the N at seeding (trt 2). Again, this was particularly evident for post-anthesis applications and to a lesser extent when applying at the boot stage. On average, split applications of N at the boot stage and post-anthesis raised grain protein by 0.22 and 0.24% for the top sites and by 0.26 and 0.33% for the bottom sites, respectively. The greater protein increase with bottom yielding sites likely occurred because there was less yield potential to dilute protein increases. However, few of these split applications proved economic because of the yield loss associated with gaining higher protein and the added cost of split application.

The economics for each treatment when considering the bottom 8 yielding sites, the top 8 yielding sites and all sites combined are found in tables 16-18. Each table assumes a base price of $5.84 per bushel of grain at 12.5% protein with a protein premium or discount of $0.6/%/bu and an N cost of $0.5/lb, regardless of product used. In addition, an extra cost of $5/ac is assigned to all split applications. The last column of each table shows the gross returns minus the variable costs of N and split applications so that a fair comparison of economic returns can be made between treatments. Treatment #2 where all the N is side-banded at seeding at 100 lb N/ac is the check for comparison. Only treatment 4 from the top yielding site/years combination generated a little more income (Table 18). All other comparisons generated less income. It would appear split applications are not economical on average. However, as mentioned at the beginning of the discussion, there is a significant site/year by treatment interaction for the grain protein data, which has an impact on economics.

Tables 19 and 20 list the gross returns minus the variable costs of N and split application for each site/year. Eight of the site/years (Indian Head 2019-2020, Redvers 2020, Yorkton 2019, Scott 2019-2020 and Melfort 2019-2020) followed the general trend where no split application of N provided greater economic returns compared to just side-banding all the N down at seeding (trt 2). Of the remaining 8 trials, where at least one of the split application treatments provided greater economic returns, these returns were extremely slim at Yorkton 2020 and only one treatment provided greater returns at Swift Current 2020. At Swift Current 2019, Redvers 2019 and Prince Albert 2020, split applications appeared more economical because the 100 lb N/ac side-banded check was either inexplicably low yielding or had low grain protein even relative to the 70 lb N/ac side-banded check. At Prince Albert in 2019, a few of the split applications were more economical, mostly due to the relatively large and unexpected yield increases as grain protein actually decreased by 0.12% on average. However, these yield increases were not statistically significant. The only site where there was some compelling evidence for an economic benefit from split applications of N was at the irrigation site near Outlook. In 2019, a few split applications of N were more economical than the 100 lb N/ac side-banded check (trt 2) due to increases in grain protein averaging 0.44%. In 2020, all but one split application of N provided greater economic returns that the check (trt 2) due to large and often significant increases in grain protein averaging 1.36%. The reason for the relatively larger protein responses to split applied N at Outlook may be related to better infiltration of N into the root system under irrigation; however, this is just speculation.

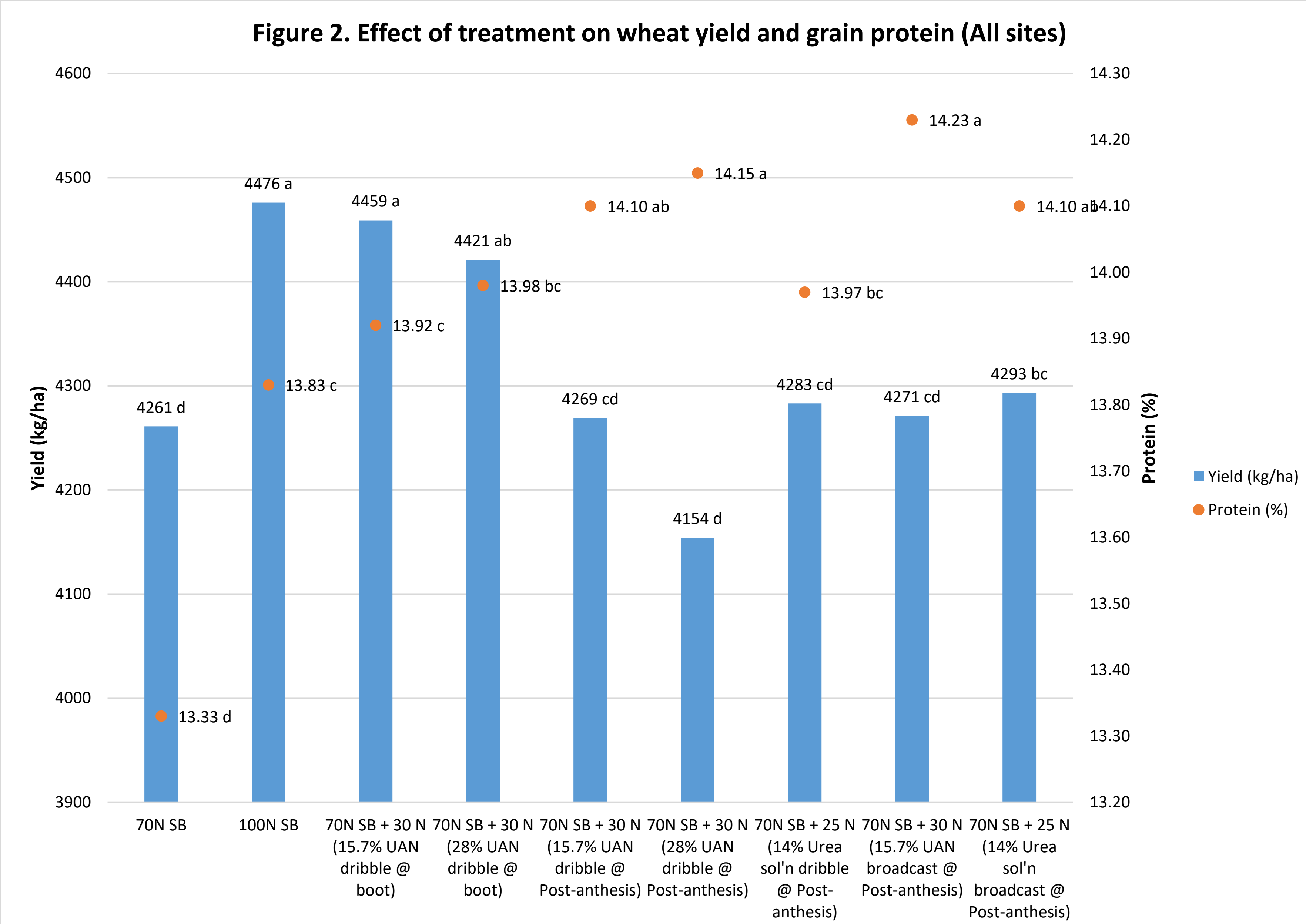
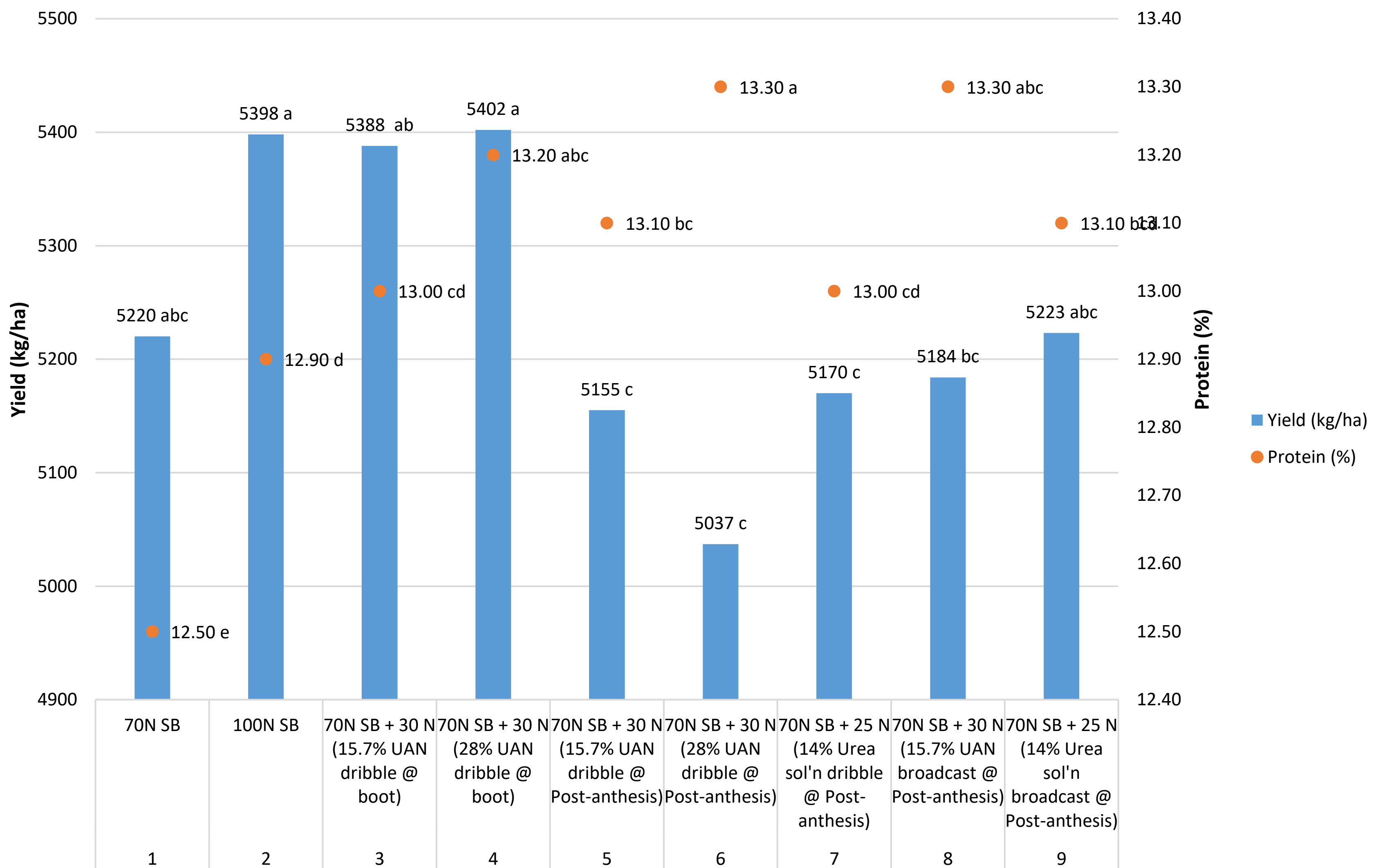


Figure 2. Effect of treatment on wheat yield and grain protein (All sites)
Yield (kg/ha)
Protein (%)
4600
4500
4400
4300
4200
4100
4000
3900
14.30
14.20
14.10
14.00
13.90
13.80
13.70
13.60
13.50
13.40
13.30
13.20
4261 d
4476 a
4459 a
4421 ab
4269 cd
4154 d
4283 cd
4271 cd
4293 bc
13.33 d
13.83 c
13.92 c
13.98 bc
14.10 ab
14.15 a
13.97 bc
14.23 a
14.10 ab
70N SB
100N SB
70N SB + 30 N (15.7% UAN dribble @ boot)
70N SB + 30 N (28% UAN dribble @ boot)
70N SB + 30 N (15.7% UAN dribble @ Post-anthesis)
70N SB + 30 N (28% UAN dribble @ Post-anthesis)
70N SB + 25 N (14% Urea sol'n dribble @ Post-anthesis)
70N SB + 30 N (15.7% UAN broadcast @ Post-anthesis)
70N SB + 25 N (14% Urea sol'n broadcast @ Post-anthesis)
Yield (kg/ha)
Protein (%)

Figure 3. Effect of treatment on wheat yield and grain protein (top 8 yielding sites)



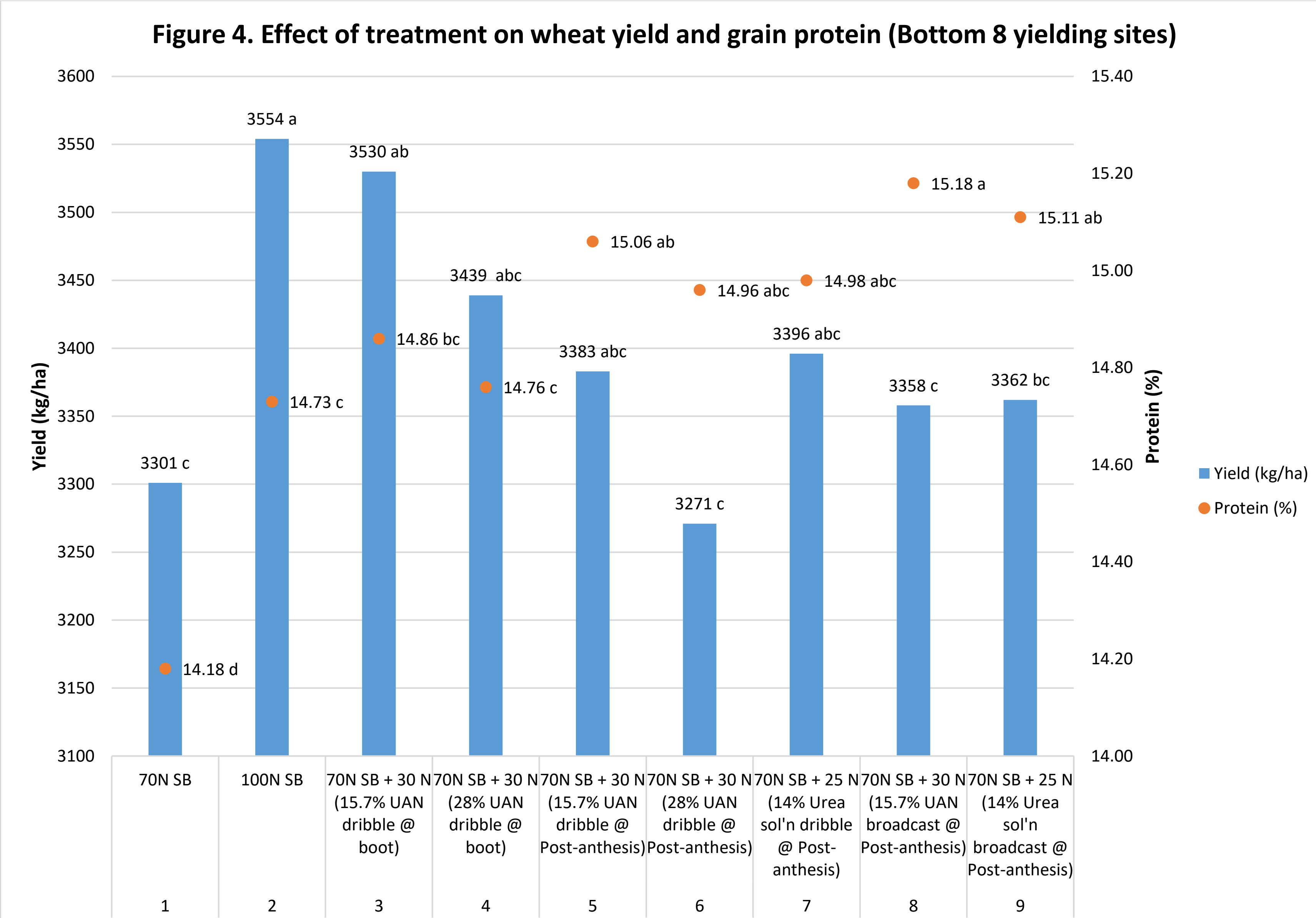


Figure 4. Effect of treatment on wheat yield and grain protein (Bottom 8 yielding sites)
Yield (kg/ha)
Protein (%)
3600
3550
3500
3450
3400
3350
3300
3250
3200
3150
3100
15.40
15.20
15.00
14.80
14.60
14.40
14.20
14.00
3301 c
3554 a
3530 ab
3439 abc
3383 abc
3271 c
3396 abc
3358 c
3362 bc
14.18 d
14.73 c
14.86 bc
14.76 c
15.06 ab
14.96 abc
14.98 abc
15.18 a
15.11 ab
70N SB
100N SB
70N SB + 30 N (15.7% UAN dribble @ boot)
70N SB + 30 N (28% UAN dribble @ boot)
70N SB + 30 N (15.7% UAN dribble @ Post-anthesis)
70N SB + 30 N (28% UAN dribble @ Post-anthesis)
70N SB + 25 N (14% Urea sol'n dribble @ Post-anthesis)
70N SB + 30 N (15.7% UAN broadcast @ Post-anthesis)
70N SB + 25 N (14% Urea sol'n broadcast @ Post-anthesis)
1
2
3
4
5
6
7
8
9
Yield (kg/ha)
Protein (%)

10. Conclusions and Recommendations

Many of the concepts this study set out to demonstrate were accomplished when analyzing the data combined over site/years. As supported by past research, dribble banding UAN earlier at the boot stage caused less flag leaf burn than applications post-anthesis. Post-anthesis applications of UAN also caused less flag leaf burn when dribble banded compared to broadcast sprayed. This was true whether concentrated (28% N) or diluted (15.7% N) UAN was dribble banded. In other words, there is no reason to dilute the UAN when dribble banding. This is intuitive as dribble band applications should provide less leaf coverage and greater safety compared to broadcast spraying. It would not be unreasonable to infer that this might also be the case for dissolved urea. However, there were no significant differences in flag leaf burn between dribble banded and broadcast applications when using dissolved urea. The lack of a difference can be attributed to already low levels of flag leaf burn with a broadcast application of dissolved urea compared to broadcast UAN. While dissolved urea has also caused less flag leaf burn in past research, the dissolved urea in this study was erroneously applied at only 25 lb N/ac instead of 30 lb N/ac to match the UAN rate. Still, the difference in flag leaf burn between broadcast UAN and dissolved urea was quite large, suggesting the difference could be attributed to more than just a 5 lb N/ac difference. Application strategies, which reduced flag leaf burn, did not usually produce a yield/protein response that maximized economic returns as anticipated, even when a healthy grain protein premium of $0.6/%/bu was considered. On average, split applications of N at the boot or post-anthesis stage raised grain protein by 0.22 and 0.24% for the top sites and by 0.26 and 0.33% for the bottom sites, respectively. But this was not enough to compensate for the associated yield losses and extra cost of the split application. Overall, it was more economical to side-band all 100 lb N/ac at seeding rather than side-band 70 lb N/ac and split apply 30 lb N/ac in the case for UAN or 25 lb N/ac in the case for dissolved urea. This held true when considering the 8 lowest yielding sites together and the 8 top yielding sites together. In other words, the benefit of split applications were not more economical for a high yielding crop compared to a low yield crop as producers would anticipate. However, this conclusion was made using the same protein spread for the low and high yielding scenarios, and in reality, protein spreads are likely to be higher when the region has a bumper crop with low protein and high protein wheat is in short supply. There were a few cases where split applications of nitrogen to raise grain protein were economical. The strongest cases occurred at Outlook where grain protein responded well to a number of the split applications of N, resulting in substantial economic gains. Outlook is an irrigation site, and applications of late season N may have leached more successfully into the root zone. However, this is speculation. Overall, there was little evidence to support the economic use of split nitrogen to increase grain protein. This practice should be considered more of a rescue treatment for under fertilized wheat rather than a planned practice.

Supporting Information

1. Acknowledgements:

This project was funded through the Saskatchewan Wheat Development Commission.

2. Appendices

Note 1. Explanation of site removal from the combined flag leaf burn analysis

Sites that rated all reps of treatments 3-4 as zero have been removed from the combined analysis. This should not have been done as fertilizer flag leaf burn ratings are really an assessment of actual fertilizer burn plus other causes of leaf senescence. Assuming no damage on treatments 3-4 is not correct. Assuming treatments 1-2 are zero is also problematic as it makes fertilizer burn appear worse for the remaining treatments. When the whole trial is rated blindly, the ratings for treatments 1-2 is an indication of damage resulting from abiotic and biotic factors other than fertilizer burn and the difference between the other treatments and treatments 1-2 is a measure of fertilizer burn.

Note 2. Explanation of N rate calculation error for dissolved urea

All late season applications of N were intended to be applied at 30 lb N/ac. All UAN treatments were applied at 30 lb N/ac but the dissolved urea treatments (# 7 and 9) were applied at 24.8 lb N/ac due to a calculation error. The concentration of N in liquid fertilizer is express as percent based on weight. UAN has 2.98 lb N/US gallon and a US gallon of UAN weighs 10.63 lbs. Thus UAN is 28 percent N by weight (2.98 lb N/10.63 lb/ US gal of UAN * 100% =28% N). Mistakenly, it was thought cutting UAN in half with water would decreased the UAN to 14% N. This is not correct as the added water in the 50/50 UAN to water mixture only weighs 8.34 lb/US gal compared to the 10.63 lb/ US gal of UAN. Thus cutting UAN in half with water creates 15.7% N on a weight basis and not 14% (2.98 lb N/(10.63 lb of UAN +8.34 lb of water)*100% = 15.7% N).

A 14% N solution of dissolved urea was successfully created by dissolving 3.66 lb urea per US gal of water (3.66 lb urea *0.46 lbN/lb urea/(3.66 lb urea + 8.34 lb water)*100% = 14% N. It was erroneously thought applying the same volumes of what was thought to be 14%N UAN and 14% N dissolved urea would supply the same amount of actual N /ac. This would not have been correct even if both solutions were 14% N because the densities of two solutions were not same and % N is based on weight basis. Through experimentation it was discovered that adding 3.66 lb of urea to 1 US gallon resulted in 1.35 US gallons of solution. Thus every US gal of solution contained 1.24 lb N/US gal (1.68 lb N/1.35 US gal).

While applying 20 US gal/ac of 15.7% N UAN or 10 US gal/ac of 28% N UAN did supply 30 lb N/ac, applying 20 US gal/ac of 14% N dissolved urea only supplied 24.8 lb N/ac (20 US gal * 1.24 lb N/US gal) and not 30 lb N/ac as intended.

Table 10. Main Effect of Nitrogen Rate, Post Emergent Nitrogen Rate, Post Emergent Nitrogen Product, Post Emergent Application Method, Post Emergent Application Timing on wheat flag leaf burn at Indian Head, Melfort, Outlook, Prince Albert, Redvers, Scott, Swift Current and Yorkton in 2020.

	Flag Leaf Burn							
	I.H.	**Melfort**	**Outlook**	**P.A.**	**Redvers**	**Scott**	**S.C.**	**Yorkton**
	------------------------------------%---------------------------------							
1. 70 lb N/ac side-banded	1.1 c	NA	7.4 c	NA	NA	NA	NA	20.2 a
2. 100 lb N/ac side-banded	0.8 c	NA	3.8 c	NA	NA	NA	NA	19.9 a
3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ boot	2.0 c	2.5 c	4.5 c	2.4 c	1.1 c	NA	NA	NA
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	2.6 c	4.9 b	4.0 c	1.8 c	4.4 bc	NA	NA	NA
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	11.8 b	15.5 a	6.4 c	27.6 a	4.3 b	NA	11.7 a	21.4 a
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	12.1 b	14.0 a	7.4 c	22.6 a	5.5 b	NA	4.5 a	23.6 a
7. 70 lb N/ac side-banded + 25[1] lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	4.2 c	14.3 a	5.4 c	13.1 b	10.5 b	NA	6.8 a	20.4 a
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	23.3 a	17.1 a	56.0 a	25.3 a	25.3 a	NA	8.1 a	21.5 a
9. 70 lb N/ac side-banded + 25[1] lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	4.5 c	16.2 a	42.0 b	6.4 bc	10.5 b	NA	6.5 a	16.7 a
P-values	<0.00001	<0.00001	<0.00001	<0.00001	0.000011	NA	NS	NS
L.S.D.	4.8	4.3	6.5	7.24	6.5	NA	NS	NS
NA: flag leaf burn ratings were assumed to be 0 with blind rating or different rating system used.								

Table 11. Main Effect of Nitrogen Rate, Post Emergent Nitrogen Rate, Post Emergent Nitrogen Product, Post Emergent Application Method, Post Emergent Application Timing on wheat flag leaf burn at Indian Head, Melfort, Outlook, Prince Albert, Redvers, Scott, Swift Current and Yorkton in 2019.								
	Flag Leaf Burn							
	I.H.	**Melfort**	**Outlook**	**P.A.**	**Redvers**	**Scott**	**S.C.**	**Yorkton**
	------------------------------------%-----------------------------------							
1. 70 lb N/ac side-banded	NA	NA	0.5 c	NA	28.5 b	NA	NA	4.1 c
2. 100 lb N/ac side-banded	NA	NA	0.4 c	NA	29.8 b	NA	NA	3.4 c
3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7 % UAN dribble banded @ boot	5.3 d	NA	0.5 c	11.3 ab	21.2 bc	NA	NA	4.8 c
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	5.5 d	NA	0.8 c	13.3 ab	22.4 bc	NA	NA	3.0 c
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	22.9 b	9.0 a	1.8 c	11.3 ab	48.1 a	NA	NA	35.1 a
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	19.9 bc	11.5 a	10.5 b	11.7 ab	29.9 b	NA	NA	36.4 a
7. 70 lb N/ac side-banded + 25[1] lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	12.8 c	3.4 a	8.6 b	4.6 c	35.5 ab	NA	NA	23.0 b
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	31.9 a	3.5 a	26.8 a	17.5a	34.8 ab	NA	NA	36.4 a
9. 70 lb N/ac side-banded + 25[1] lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	11.4 cd	5.7 a	12.1 b	10.4 bc	10.8 c	NA	NA	18.2 b
P-values	<0.00001	NS	<0.00001	0.03	0.012	NA	NA	<0.00001
L.S.D.	6.3	NS	3.3	6.4	17.0	NA	NA	8.9
NA: flag leaf burn ratings were assumed to be zero without actual blind rating or different rating system used.								

Table 12. Main Effect of Nitrogen Rate, Post Emergent Nitrogen Rate, Post Emergent Nitrogen Product, Post Emergent Application Method, Post Emergent Application Timing on wheat yield at Indian Head, Melfort, Outlook, Prince Albert, Redvers, Scott, Swift Current and Yorkton in 2020.									
	Yield								
	I.H.	**Melfort**	**Outlook**	**P.A.**	**Redvers**	**Scott**	**S.C.**	**Yorkton**	**All Sites**
	----------------------------------kg/ha---------------------------------								
1) 70 lb N/ac side-banded	4401 c	4639 a	3517 a	4589 a	3958 a	4951 b	3224 a	1973 a	3906
2) 100 lb N/ac side-banded	4723 a	4910 a	3948 a	4202 a	4605 a	5266 a	3453 a	2003 a	4139
3) 70 lb N/ac side-banded + 30 lb N/ac of 15.7 % UAN dribble banded @ boot	4637 ab	4632 a	3971 a	4814 a	4111 a	5003 ab	3721 a	1984 a	4109
4) 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	4515 bc	4644 a	3899 a	5263 a	4093 a	4962 b	3467 a	1968 a	4101
5) 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	4468 c	4424 a	3678 a	4165 a	3743 a	4598 c	3426 a	2114 a	3827
6) 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	4419 c	3976 a	3524 a	3936 a	3456 a	4674 c	3294 a	1986 a	3658
7) 70 lb N/ac side-banded + 25[1] lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	4475 c	4597 a	3594 a	4495 a	4017 a	4811 bc	3406 a	1989 a	3923
8) 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	4465 c	4729 a	3573 a	4534 a	3886 a	4848 bc	2914 a	2012 a	3870
9) 70 lb N/ac side-banded + 25[1] lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	4484 bc	4507 a	3631 a	4248 a	3886 a	4852 bc	2949 a	2052 a	3826
P-values	0.005197	NS	0.064722	NS	NS	0.002577	NS	NS	
L.S.D.	158	NS	360	NS	NS	274	NS	NS	
[1]Rate was not 30 lb N/ac as originally intended due to calculation error described in appendix									

Table 13. Main Effect of Nitrogen Rate, Post Emergent Nitrogen Rate, Post Emergent Nitrogen Product, Post Emergent Application Method, Post Emergent Application Timing on wheat yield at Indian Head, Melfort, Outlook, Prince Albert, Redvers, Scott, Swift Current and Yorkton in 2019.

	Yield								
	I.H.	**Melfort**	**Outlook**	**P.A.**	**Redvers**	**Scott**	**S.C.**	**Yorkton**	**All Sites**
	----------------------------------kg/ha----------------------------------								
1. 70 lb N/ac side-banded	3330bc	5179 bc	7213 a	3538 a	5179 a	3830 a	3038 a	5611 a	4615 a
2. 100 lb N/ac side-banded	3598 a	5566 a	7909 a	3544 a	4754 a	4018 a	3263 a	5856 a	4814 a
3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7 % UAN dribble banded @ boot	3422 ab	5331 ab	7489 a	3936 a	5144 a	3857 a	3242 a	6056 a	4810 a
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	3388 b	5111 bc	7795 a	3600 a	5202 a	3858 a	3239 a	5729 a	4740 a
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	3226 bcd	5071 cd	7623 a	3623 a	5206 a	4002 a	3251 a	5688 a	4711 a
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	3378 bc	4837 d	7722 a	3720 a	5020 a	3759 a	3055 a	5715 a	4651 a
7. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	3188 cd	5123 bc	7199 a	3846 a	4942 a	3950 a	3177 a	5716 a	4643 a
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	3266 bc	5161 bc	7182 a	4026 a	4918 a	4110 a	3075 a	5636 a	4672 a
9. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	3045 d	5232 bc	7437 a	3952 a	5012 a	4059 a	3325a	6017 a	4760 a
P-values	0.000593	0.000462	NS	NS	NS	NS	NS	NS	NS
L.S.D.	197.8129	243.635	NS	NS	NS	NS	NS	NS	NS

Table 14. Main Effect of Nitrogen Rate, Post Emergent Nitrogen Rate, Post Emergent Nitrogen Product, Post Emergent Application Method, Post Emergent Application Timing on wheat protein at Indian Head, Melfort, Outlook, Prince Albert, Redvers, Scott, Swift Current and Yorkton in 2020.

	Protein								
	I.H.	**Melfort**	**Outlook**	**P.A.**	**Redvers**	**Scott**	**S.C.**	**Yorkton**	**All Sites**
	------------------------------------%----------------------------------								
1. 70 lb N/ac side-banded	12.5 f	11.6 c	10.8 e	13.6 b	14.4 c	12.5 b	10.6 d	17.2 a	12.9
2. 100 lb N/ac side-banded	14.0 a	11.9 abc	11.1 de	13.6 b	14.8 b	13.2 a	13.1 ab	17.7 a	13.7
3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7 % UAN dribble banded @ boot	12.9 e	12.0 abc	11.8 cd	14.9 a	14.7 bc	13.4 a	14.0 a	17.6 a	13.9
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	13.0 de	12.3 ab	11.7 cde	15.4 a	14.7 bc	13.5 a	13.1 ab	17.5 a	13.9
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	13.2 de	12.1 abc	13.9 a	14.8 ab	14.7 bc	13.4 a	12.6 bc	17.7 a	14.1
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	13.3 cd	12.4 a	12.0 bcd	14.6 ab	15.2 a	13.4 a	11.7 c	18.0 a	13.8
7. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	12.9 e	11.8 bc	12.9 b	14.7 ab	15.2 a	13.3 a	12.2 bc	17.9 a	13.8
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	13.9 ab	11.8 bc	12.9 b	15.4 a	15.4 a	13.7 a	12.4 bc	17.7 a	14.2
9. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	13.6 bc	11.9 abc	12.4 bc	14.7 ab	15.2 a	13.5 a	12.3 bc	17.8 a	13.9
P-values	<0.00001	0.054787	0.000015	0.024175	0.000027	0.028407	0.0000 24	NS	
L.S.D.	0.3	0.5	0.9	1.2	0.3	0.6	1.0	NS	

Table 15. Main Effect of Nitrogen Rate, Post Emergent Nitrogen Rate, Post Emergent Nitrogen Product, Post Emergent Application Method, Post Emergent Application Timing on wheat protein at Indian Head, Melfort, Outlook, Prince Albert, Redvers, Scott, Swift Current and Yorkton in 2019.

	Protein								
	I.H.	**Melfort**	**Outlook**	**P.A.**	**Redvers**	**Scott**	**S.C.**	**Yorkton**	**All Sites**
	-----------------------------------%----------------------------------								
1. 1. 70 lb N/ac side-banded	15.6 c	11.3 a	12.0 c	13.7 a	14.4 e	14.5 cde	16.9 a	12.1 a	13.8 d
2. 2. 100 lb N/ac side-banded	15.9 bc	11.5 a	12.2 bc	14.6 a	14.5 de	14.7 ab	16.1 a	12.7 a	**21.5.1.1.1 d**
3. 3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7 % UAN dribble banded @ boot	15.6 c	11.5 a	12.3 bc	14.2 a	14.7 cde	14.7 bc	16.5 a	12.4 a	14.0 cd
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	15.7 c	11.3 a	12.7 bc	14.0 a	14.8 bcd	14.9 a	16.7 a	12.7 a	14.1 bc
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	16.0 b	11.5 a	12.9 b	14.3 a	15.0 abc	14.5 cd	16.8 a	12.5 a	14.2 bc
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	15.8 c	11.4 a	13.8 a	15.0 a	15.3 a	14.6 bcd	17.5 a	12.6 a	14.5 a
7. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	16.0 b	11.6 a	12.0 c	14.5 a	15.1 ab	14.6 bcd	16.6 a	12.4 a	14.1 bc
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	16.6 a	11.4 a	12.5 bc	14.6 a	15.2 ab	14.3 e	17.5 a	12.4 a	14.3 ab
9. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	16.8 a	11.7 a	12.1 bc	14.5 a	15.0 abc	14.5 cde	17.5 a	12.3 a	14.3 ab
P-values	<0.00001	NS	0.000523	NS	0.001682	0.000092	NS	NS	
L.S.D.	0.34	NS	0.72	NS	0.43	0.18	NS	NS	

Table 16 All 16 site/years economics combined[1]					
	Yield (kg/ha)	**Yield (bu/ac)**	**Protein (%)**	**($/bu)**	**Gross-N cost and cost of any split application/ac**
1. 70 lb N/ac side-banded	4261	63.4	13.3	6.34	398.31
2. 100 lb N/ac side-banded	4476	66.6	13.8	6.64	437.07
3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7 % UAN dribble banded @ boot	4459	66.3	13.9	6.69	433.97
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	4421	65.8	14.0	6.73	432.55
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	4269	63.5	14.1	6.80	421.91
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	4154	61.8	14.2	6.83	412.13
7. 70 lb N/ac side-banded + 25 lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	4283	63.7	14.0	6.72	420.86
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	4271	63.5	14.2	6.88	427.07
9. 70 lb N/ac side-banded + 25 lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	4293	63.9	14.1	6.80	426.84

[1]Each table assumes a base price of $5.84 per bushel at 12.5% with a protein premium of $0.6/%/bu and an N cost of $0.5/lb regardless of product used. In addition, an extra cost of $5/ac is assumed for all split applications.

Table 17 Bottom 8 yielders economics combined.[1]					
	Yield (kg/ha)	**Yield (bu/ac)**	**Protein (%)**	**($/bu)**	**Gross-N cost and cost of any split application**
1. 70 lb N/ac side-banded	3301	49.1	14.2	6.86	333.42
2. 100 lb N/ac side-banded	3554	52.9	14.7	7.16	373.61
3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7 % UAN dribble banded @ boot	3530	52.5	14.9	7.28	372.35
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	3439	51.2	14.8	7.22	359.43
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	3383	50.3	15.1	7.40	362.47
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	3271	48.7	15.0	7.34	347.22
7. 70 lb N/ac side-banded + 25 lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	3396	50.5	15.0	7.34	363.37
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	3358	50.0	15.2	7.46	362.72
9. 70 lb N/ac side-banded + 25 lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	3362	50.0	15.1	7.40	362.66
[1]Each table assumes a base price of $5.84 per bushel at 12.5% with a protein premium of $0.6/%/bu and an N cost of $0.5/lb regardless of product used. In addition, an extra cost of $5/ac is assumed for all split applications.					

Table 18 Top 8 yielders economics combined.[1]					
	Yield (kg/ha)	**Yield (bu/ac)**	**Protein (%)**	**($/bu)**	**Gross-N cost and cost of any split application**
1. 70 lb N/ac side-banded	5220	77.7	12.5	5.84	450.07
2. 100 lb N/ac side-banded	5398	80.3	12.9	6.08	483.31
3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ boot	5388	80.2	13.0	6.14	482.22
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	5402	80.4	13.2	6.26	493.14
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	5155	76.7	13.1	6.20	465.53
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	5037	74.9	13.3	6.32	463.64
7. 70 lb N/ac side-banded + 25 lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	5170	76.9	13.0	6.14	464.8
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	5184	77.1	13.3	6.32	477.46
9. 70 lb N/ac side-banded + 25 lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	5223	77.7	13.1	6.20	474.31

[1]Each table assumes a base price of $5.84 per bushel at 12.5% with a protein premium of $0.6/%/bu and an N cost of $0.5/lb regardless of product used. In addition, an extra cost of $5/ac is assumed for all split applications.

Table 19. Gross Returns ($/ac) – Cost of N and split application for all locations ($/ac) in 2020								
	$/ac							
	Indian Head	**Melfort**	**Outlook**	**Prince Albert**	**Redvers**	**Scott**	**Swift Current**	**Yorkton**
1. 70 lb N/ac side-banded	345.41	328.72	215.67	407.75	374.30	395.15	189.02	219.62
2. 100 lb N/ac side-banded	423.62	350.35	244.60	356.36	443.69	441.55	269.29	216.17
3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ boot	364.47	326.78	264.30	465.37	381.14	417.58	316.43	206.86
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	355.44	338.11	254.23	537.38	380.15	421.52	264.03	203.41
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	359.14	314.60	309.77	391.46	344.59	380.46	246.45	225.82
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	359.50	286.10	235.44	360.81	327.07	386.60	206.97	215.00
7. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	350.77	314.66	269.30	421.83	389.98	396.31	231.84	213.24
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	387.81	327.40	266.63	457.36	382.37	418.16	196.25	213.67
9. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	377.62	311.43	257.21	397.58	376.29	410.95	194.64	219.44

Table 20. Gross Returns ($/ac) – Cost of N and split application for all locations ($/ac) in 2019								
	$/ac							
	Indian Head	**Melfort**	**Outlook**	**Prince Albert**	**Redvers**	**Scott**	**Swift Current**	**Yorkton**
1. 70 lb N/ac side-banded	344.96	358.35	561.18	309.53	501.69	365.32	348.24	431.28
2. 100 lb N/ac side-banded	370.18	382.72	614.28	322.75	445.81	378.91	336.90	466.65
3. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ boot	337.75	358.22	582.34	344.93	490.67	354.14	342.50	465.76
4. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ boot	334.60	334.35	636.23	305.21	504.95	362.88	347.85	450.42
5. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN dribble banded @ post-anthesis	326.08	338.09	631.14	318.02	511.19	365.06	351.49	436.67
6. 70 lb N/ac side-banded + 30 lb N/ac of 28% UAN dribble banded @ post-anthesis	336.49	318.87	707.31	350.40	505.49	342.93	346.81	447.91
7. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea dribble banded @ post-anthesis	322.27	348.94	538.38	347.80	489.15	363.18	335.85	437.82
8. 70 lb N/ac side-banded + 30 lb N/ac of 15.7% UAN broadcast foliar sprayed @ post-anthesis	348.32	342.76	570.67	370.27	490.81	369.08	350.16	428.45
9. 70 lb N/ac side-banded + 30 lb N/ac of 14% Dissolved Urea broadcast foliar sprayed @ post-anthesis	325.79	362.23	566.34	358.90	491.21	370.13	382.33	458.40

<u>Abstract</u>

4. **Abstract/Summary:**

In 2019 and 2020, trials were established at 8 AgriARM locations across Saskatchewan to demonstrate the potential of increasing either wheat yield or grain protein with late season applications of N in the form of UAN or dissolved urea. All late season applications of N were intended to be applied at 30 lb N/ac to a base rate of 70 lb N/ac of side-banded urea. Due to a calculation error, dissolved urea was only applied at 25 lb N/ac. However, the results did support many of the principles the study set out to demonstrate. Earlier dribble band applications of UAN at the boot stage caused less flag leaf burn compared to post-anthesis applications. Using less concentrated forms of UAN was not necessary to reduce leaf burn when dribble banding at either stage. When applying post-anthesis, dribble banding UAN caused significantly less flag leaf burn compared a broadcast spray which caused the most damage of any treatment. Leaf injury from broadcast spraying was substantially reduced when using dissolved urea instead of UAN. While this phenomenon is supported by past study, the lower rate of N with the dissolved urea in this study would also contribute to greater crop safety. In general, split applications of N were able to raise the grain protein relative to applying all the N at seeding but they also tended to result in less yield. Protein increases and yield decreases were less pronounced with the boot stage timing compared to the post-anthesis timing. Economically, split applications did not prove to be economic because the value of the protein increases were negated by the associated yield losses even when assuming a healthy protein spread of $0.6/%/bu. This was true whether considering the all site/years combined, the top 8 yielding sites combined or the lowest 8 yielding sites combined. In other words, the benefit of split applications were not more economical for a high yielding crop compared to a low yield crop when assuming the same protein spread.