Site-specific evaluation of environmental and economic benefits of enhanced efficiency nitrogen fertilizers

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Introduction

Nitrogen fertilizer is a major expense for wheat production. Adequate N is essential to ensure good crop yield and quality. However, with increasing energy costs, nitrogen prices have increased substantially. It is essential that producers use nitrogen efficiently in order to attain the highest possible crop return per dollar invested in fertilizer.

Farmers are also being asked to take on more responsibility for environmental stewardship. Excess nitrogen in agricultural systems can have a major negative impact on environmental quality. During microbial conversion in the soil, nitrogen can release nitrous oxide, a gas with a greenhouse effect approximately 300 times that of carbon dioxide. Volatilization can lead to the movement of ammonia in air and subsequently to the water (when washed out of the air with precipitation). Enhanced eutrophication of surface water can occur when nitrogen enters the waterways from erosion and runoff. Groundwater may also be polluted by nitrate leaching. In addition, the energy used in nitrogen fertilizer production is a major energy input in crop production and the high energy consumption will contribute to climate change. Increasing efficiency of nitrogen use can minimise negative environmental effects and may increase carbon sequestration by increasing organic matter production.

In order to increase nitrogen use efficiency, one must reduce the amount of nitrogen lost to the air and water and increase the proportion utilized by the crop. Nitrogen is lost from the plant-soil system through four major pathways – volatilization, immobilization, denitrification and leaching. Ammonia or ammonium-producing sources of N can be lost via volatilization. Both ammonium and nitrate sources can be lost by immobilization. Nitrogen must convert to nitrate before it will be lost by denitrification or leaching. The potential for N loss from these pathways will therefore depend on the nitrogen source as well as on soil type and environmental conditions.

The longer nitrogen is present in the soil before the crop takes it up, the more risk there is of the nitrogen being lost to the air or water. Synchronizing the amount and timing of nitrogen availability with the N requirements of the crop will reduce environmental losses of N, while optimizing crop productivity. Therefore, nitrogen efficiency should be improved if nitrogen supply is closely matched with crop demand, both in terms of amount and timing of supply. In many production systems, particularly in wetter areas with longer growing seasons or for high value crops, nitrogen is applied in several smaller increments during the growing season, to match nitrogen availability with crop demand. An alternative method of supplying nitrogen at a gradual rate is the use of controlled release fertilizer products. Polymer-coated urea products are available that release N at a rate controlled by soil temperature. Controlled release N fertilizers could better match the timing of N release from fertilizer products to crop N uptake, thus optimizing fertilizer use efficiency, improving economics of production, reducing nitrate accumulation in the soil and reducing the risk of N movement into the air or water.

An alternate method of improving efficiency of urea nitrogen is by slowing the conversion of urea to ammonium and ammonium to nitrate. Urease inhibitors slow the conversion of urea to ammonium, while nitrification inhibitors slow the conversion of ammonium to nitrate. Slowing the conversion of urea to ammonium allows more time for urea to move into the soil where it is protected from volatilization loss. Maintaining the N in the ammonium forma for longer also reduces the risk of denitrification and leaching. As with controlled release urea, the relative benefits of urease or nitrification inhibitors will vary with environment and the risk of loss.

Producers may also choose to use split applications of nitrogen fertilizer to reduce the initial investment in nitrogen fertilizers in environments where crop yield is highly variable. If the spring is dry and the yield potential of the crop appears low, the application of N at the time of seeding may be reduced to minimise the investment in a potentially low-yielding crop. If the growing conditions then improve and the crop yield potential increases, additional nitrogen may be applied to the growing crop to attain the yield potential. With this strategy, use of in-crop assessment of crop nitrogen status would be valuable to determine if the additional nitrogen was needed by the crop. A number of different systems are available for assessing in-crop nitrogen status. These include tissue N analysis, estimation of plant chlorophyll content using the SPAD meter or the Green-seeker, and estimation of polyphenol content using the Dualex. If the crop is deficient in nitrogen, the probability of attaining an increase in crop yield with application of nitrogen would be greater than if the crop was adequately supplied with nitrogen. Therefore an accurate assessment of nitrogen status would be a valuable tool for optimising nitrogen management.

Benefits of CRU, urease or nitrification inhibitors, or split applications vary with environment. If soils are dry, N losses from denitrification and leaching are low, reducing the potential benefit from split applications or CRU, although split applications to reduce initial N investment could still reduce economic risk. If soils are wet, losses are higher and potential benefit is greater. This study will assess where CRU, urease and nitrification inhibitors or split N applications are likely to be of benefit, by determining the effect of microclimate on N losses and the performance of N management. It will also evaluate ways to assess crop N status in order to predict the likelihood of a response to N application and thus determine the need for in-crop N applications. This will provide detailed information to producers, the fertilizer industry and policy-makers as to the conditions where utilization of enhanced efficiency fertilizers or split applications of N will provide economic and/or environmental benefits.

Objectives

To determine:

1) The economic benefits of using split N applications, control release urea (CRU), or urease and nitrification inhibitors as compared to traditional N application methods under various environments.
2) The effect of microclimate on the relative effectiveness of various N management practices, including controlled release fertilizers, urease and nitrification inhibitors and split N applications.
3) If N management strategies should be altered depending on seeding date.

4) The ability of various methods of in-crop determinations of N status to predict an economic response to in-crop N applications.

Materials and Methods

Field research trials were established at two locations near Brandon, MB, on a silty clay soil (Brandon) and a clay loam soil (Phillips). At each location, two sites were sown in an upper and lower slope position to provide two contrasting microclimates. Hard red spring wheat was seeded at two dates at each slope position early in the spring and in late May, three to four weeks later. This provided another set of microenvironments, as changing the seeding date alters the weather conditions experienced by the crop at each as each growth stage and influences the length of growth and grain-filling.

Treatments

1) Control – no N
2) Fall banded urea N at 1.0 x recommended rate
3) Fall banded CRU at 1.0 x recommended rate
4) Spring side-banded urea N at 0.5 x recommended rate
5) Spring side-banded urea N at 1.0 x recommended rate
6) Spring side-banded urea N at 1.5 x recommended rate
7) Spring side-banded CRU at 0.5 x recommended rate
8) Spring side-banded CRU at 1.0 x recommended rate
9) Spring side-banded CRU at 1.5 x recommended rate
10) Super U at recommended rate (broadcast before seeding)
11) Agrotain Plus at 1.0 x recommended rate (dribble on seed row))
12) Split N application 1 - 0.5 side-banded at seeding and 0.5 dribble-banded as UAN at early tillering (Feekes stage 2-3) 2” off seed row
13) Split N application 2 - 0.5 side-banded at seeding and 0.5 dribble-banded as UAN at late tillering to early stem extension (Feekes stage 5-6) 2” off seed row

Spring banded treatments were applied as a side-bandduring the seeding operation. Recommended N rate was based on soil testing and a moderate target yield. In 2007, the rate of application was 60 kg ha^{-1}. The 1.5 x recommended rate served as the N-saturation treatment for the in-crop N measurement. All treatments received 30 kg P_2O_5 ha^{-1} as monoammonium phosphate, seed-placed. Weeds, diseases and insects were controlled using registered pesticides.

Measurements

1) Soil nutrient content, pH, conductance, soil texture, and organic carbon to 60 cm.
2) Gravimetric soil moisture to 60 cm at seeding
3) Soil moisture and temperature at 7.5 cm depth, using dataloggers.
4) Air temperature and rainfall
5) Date of emergence and plant stand density.
6) Tissue N, and crop assessment with SPAD, GreenSeeker and Dualex (GER Spectroradiometer) meters immediately prior to fertilization at Feekes 2-3 and 4-6
7) Plant biomass and tissue N at heading.
8) Grain yield, straw yield, N concentration, harvest index and N harvest index.
9) Soil N content to 60 cm at harvest

The study was arranged as a split plot factorial experiment with four replicates, with seeding dates as the main plots and fertilizer treatments as the sub-plots, giving 2 locations x 2 slope positions x 2 seeding dates x 13 treatments x 4 replications = 416 plots per year. Statistical analysis was conducted using contrast analysis under Proc Mixed of SAS, with differences considered significant at $p<0.05$.

Results

The growing season began with relatively wet conditions and moderate temperatures. However, In July, the weather became very hot and dry, with little to no rainfall through July and August. Therefore, yields were restricted by drought and excess heat.

Stand Density

Crop emergence was good due to ample moisture after seeding (data not presented). Stand was higher with late than early seeding and on upper than lower slope positions at the Brandon site. At the Phillips site, stand was also higher with later than early seeding, but was higher on the lower than upper slope position. The Brandon site is a poorly-drained heavy textured location which may have reduced stand density. The restricted drainage may have affected stand density at the Brandon location, while the extra moisture on the lower sites may have been beneficial at the Phillips location.

Biomass Yield at Heading

Biomass yield was heading was assessed by harvesting two-one meter lengths of row, drying at 60C then weighing. Biomass yield at heading was affected by location, area, date and treatment (Table 1 to Table 3).

Table 1: ANOVA for effect of ANOVA table for effects of treatment, area and date on grain yield at two locations

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	Brandon			Phillips		
Effect	DF	F Value	Pr > F	DF	F Value	Pr > F
treat	12	1.91	0.037	12	3.24	0.0004
area	1	27.49	<.0001	1	633.96	<.0001
area*treat	12	1.12	0.3484	12	0.75	0.7023
date	1	0.02	0.8851	1	0.17	0.6774
date*treat	12	1.18	0.2988	12	0.81	0.6365
area*date	1	15.15	0.0001	1	1.45	0.23
area*date*treat	12	0.96	0.4894	12	1.2	0.2862

Table 2: Effect of nitrogen source, rate and timing on biomass yield at heading (T ha^{-1}) on upper and lower slope positions, with early and late seeding dates – Brandon 2007

			Lower			Upper		
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean
Control	0	Control	5.97	5.38	5.68	6.09	6.03	6.06
Urea	1	Fall Band	6.29	6.77	6.53	6.34	6.67	6.51

CRU	1	Fall Band	6.50	5.83	6.16	6.31	7.16	6.73
Urea	0.5	Spring Band	6.98	5.67	6.33	7.27	7.06	7.16
Urea	1	Spring Band	6.60	5.73	6.16	6.58	7.07	6.82
Urea	1.5	Spring Band	5.54	6.25	5.89	6.66	8.14	7.40
CRU	0.5	Spring Band	6.02	5.74	5.88	6.84	7.41	7.12
CRU	1	Spring Band	5.89	5.16	5.53	6.58	7.64	7.11
CRU	1.5	Spring Band	5.62	5.26	5.44	6.08	7.98	7.03
SuperU	1	Spring Broadcast	6.47	5.87	6.17	6.93	6.85	6.89
Agrotain	1	Spring Dribbled	7.27	5.85	6.56	6.87	7.19	7.03
Urea-UAN	1	Split-Early	6.20	4.49	5.35	5.85	8.56	7.21
Urea-UAN	1	Split-Late	5.95	4.60	5.28	5.82	4.56	5.19
		Mean	6.25	5.58	5.92	6.48	7.10	6.79
MSE			0.3255	0.6156	0.3482	0.4908	0.8803	0.5312
Contrasts								
Fall urea vs fall CRU			ns	ns	ns	ns	ns	ns
Spring urea vs fall urea			ns	ns	ns	ns	ns	ns
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			0.0400	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	0.0319	0.0176
CRU vs SuperU			ns	ns	ns	ns	ns	ns
CRU vs Agrotain			0.0040	ns	0.0393	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns

Biomass yield at the Brandon site showed little response to N application (Table 1 and Table 3). The Agrotain Plus treatment gave higher yield than the CRU on the early-seeded lower slope position, but did not differ from other treatments in the other comparisons. The late split application treatment performed poorly, producing lower biomass at heading than the untreated urea on the upper slope positions. The poorer biomass yield may be due to crop damage contact between the dribble band and the foliage.

Table 3: Effect of nitrogen source, rate and timing on biomass yield at heading (T ha^{-1}) on upper and lower slope positions, with early and late seeding dates - Phillips 2007

			Lower			Upper		
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean
Control	0	Control	4.77	5.21	4.99	3.26	3.12	3.19
Urea	1	Fall Band	5.01	5.02	5.02	3.35	2.45	2.90
CRU	1	Fall Band	5.75	5.66	5.70	3.18	3.54	3.36
Urea	0.5	Spring Band	5.34	5.46	5.40	3.72	3.25	3.49

Urea	1	Spring Band	5.73	5.36	5.55	3.29	3.80	3.54
Urea	1.5	Spring Band	5.36	5.48	5.42	3.66	3.90	3.78
CRU	0.5	Spring Band	4.63	5.37	5.00	3.55	3.06	3.31
CRU	1	Spring Band	5.64	5.35	5.50	3.84	3.36	3.60
CRU	1.5	Spring Band	5.15	5.56	5.36	2.62	3.15	2.89
SuperU	1	Spring Broadcast	5.35	5.53	5.44	3.23	3.48	3.35
Agrotain	1	Spring Dribbled	5.11	5.61	5.36	3.52	3.42	3.47
Urea-UAN	1	Split-Early	4.78	4.99	4.88	3.33	2.96	3.15
Urea-UAN	1	Split-Late	5.09	4.76	4.93	2.70	2.95	2.83
		Mean	5.21	5.34	5.27	3.33	3.26	3.30
MSE			0.3696	0.2454	0.2232	0.2547	0.2606	0.1891
Contrasts								
Fall urea vs fall CRU			ns	ns	0.0306	ns	0.0034	ns
Spring urea vs fall urea			ns	ns	ns	ns	0.0004	0.0111
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	0.0372	ns	0.0215	ns
Spring urea vs late split			ns	ns	0.0500	ns	0.0196	0.0048
CRU vs SuperU			ns	ns	ns	ns	ns	ns
CRU vs Agrotain			ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns

At the Phillips site, fall banded urea produced lower biomass yields than spring banded urea on the upper slope position while the difference was not significant on the lower slope position (Table 3). Use of CRU instead of urea for fall banding led to higher biomass yields both in the upper and lower slope positions, although the difference on the upper slope position was significant only at $p<0.0669$. The split applications performed poorly at the Phillips site, particularly on the lower slope position. The use of CRU, SuperU or Agrotain Plus had no significant effect on biomass yield at heading as compared to application of untreated urea.

Grain Yield

Grain yield was higher at the Brandon site than the Phillips site, particularly on the upper slope positions (Table 4 to Table 6). At the Brandon site, the upper slope position produced higher grain yield than the lower slope positions with the late seeding date, although yields were comparable in the two slope positions with the early seeding date. The results with grain yield followed the same pattern as biomass yields (Table 4). At the Phillips site, grain yield was 60% higher on the lower slope with early seeding and 40% higher on the lower slope position with late seeding as compared to the yields on the upper slope position (Table 4 and Table 6). Presumably, the early seeded crop had a greater yield potential than the later seeded crop, and the higher moisture availability on the lower slope position allowed the crop to capture a greater proportion of that yield potential

Table 4: **ANOVA table for effects of treatment, area and date on grain yield at two locations**

Grain yield was not affected greatly by nitrogen management at the Brandon site (Table 5). At the early seeding date, there were no significant effects of nitrogen. At the later seeding date, the CRU and uncoated urea tended to produce higher grain yield than the SuperU. However, the differences were not consistently significant.

At the Phillips site, grain yield was generally lower with fall-banded urea than with spring-banded urea, particularly with late seeding (Table 6). Use of CRU tended to produce higher grain yields than uncoated urea when fall-banded. The differences between fall-banded urea and CRU were greater on the upper slope position, possibly because leaching losses from the fall-applied N were greater on the upper slope positions in the rolling topography of the Phillips site. The fall-banded CRU generally produced yields statistically similar to that of the spring-banded urea, although numerically, the fall-banded CRU was generally slightly lower than the spring-banded urea.

	Brandon			Phillips		
Effect	DF	F Value	Pr > F	DF	F Value	Pr > F
treat	12	1.46	0.1459	12	4.35	<.0001
area	1	12.8	0.0005	1	711.81	<.0001
area*treat	12	0.63	0.8174	12	2.03	0.0253
date	1	182.76	<.0001	1	481.8	<.0001
date*treat	12	0.6	0.8418	12	1.1	0.364
area*date	1	6.83	0.0099	1	73.34	<.0001
area*date*treat	12	0.25	0.9947	12	1.21	0.2834

Table 5: Effect of nitrogen source, rate and timing on wheat grain yield (T ha^{-1}) on upper and lower slope positions, with early and late seeding dates – Brandon 2007

			Lower			Upper		
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean
Control	0	Control	3.45	2.77	3.11	3.56	3.09	3.33
Urea	1	Fall Band	3.25	2.71	2.98	3.51	3.05	3.28
CRU	1	Fall Band	3.10	2.56	2.83	3.21	2.84	3.03
Urea	0.5	Spring Band	3.45	2.70	3.07	3.51	2.64	3.08
Urea	1	Spring Band	3.24	2.67	2.95	3.38	3.11	3.24
Urea	1.5	Spring Band	3.22	2.48	2.85	3.39	2.98	3.19
CRU	0.5	Spring Band	3.51	2.78	3.14	3.42	3.06	3.24
CRU	1	Spring Band	3.44	2.72	3.08	3.53	2.99	3.26
CRU	1.5	Spring Band	3.38	2.59	2.98	3.27	2.68	2.98
SuperU	1	Spring	3.22	2.49	2.86	3.40	2.75	3.08

AgrotainPlus	1	Broadcast Spring Dribbled	3.36	2.61	2.98	3.14	2.75	2.95
Urea-UAN	1	Split-Early	3.31	2.65	2.98	3.25	3.06	3.16
Urea-UAN	1	Split-Late	3.48	2.61	3.04	3.34	2.75	3.05
		Mean	3.34	2.64	2.99	3.38	2.91	3.14
MSE			0.1238	0.0723	0.0734	0.2267	0.2156	0.1792
Contrasts								
Fall urea vs fall CRU			ns	ns	ns	ns	ns	ns
Spring urea vs fall urea			ns	ns	ns	ns	ns	ns
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	ns	ns
CRU vs SuperU			ns	0.0249	0.0356	ns	ns	ns
CRU vs Agrotain			ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns

On the lower slope position at the Phillips site, grain yield was higher with the uncoated spring-banded urea than with the dribble-banded UAN with Agrotain Plus, especially with early seeding. Apparently losses from the surface –dribble banded application restricted yields under the high productivity conditions of the early-seeded lower slope position. Yields were also lower with the late split application than with the uncoated urea, possibly because of losses from the surface application, or early season constraints in available N as only ½ of the rate of N was applied at seeding. Yields with the ½ rate of nitrogen were similar to yields when ½ of the N was applied at seeding and ½ was dribble-banded late in the growing season, indicating that the yield was not increased by the late in-crop nitrogen application. Yield was also higher with CRU than Agrotain Plus in one contrast, but generally yields did not differ among the enhanced efficiency fertilizers.

Table 6: Effect of nitrogen source, rate and timing on wheat grain yield (T ha^{-1}) on upper and lower slope positions, with early and late seeding dates – Phillips 2007

			Lower			Upper		
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean
Control	0	Control	2.54	1.92	2.23	1.69	1.25	1.47
Urea	1	Fall Band	3.22	1.97	2.60	1.68	0.97	1.33
CRU	1	Fall Band	3.19	2.15	2.67	1.94	1.44	1.69
Urea	0.5	Spring Band	3.06	2.11	2.59	2.10	1.63	1.86
Urea	1	Spring Band	3.37	2.16	2.77	1.98	1.75	1.87
Urea	1.5	Spring Band	3.26	2.17	2.72	1.92	1.54	1.73
CRU	0.5	Spring Band	2.99	2.09	2.54	2.03	1.34	1.68

CRU	1	Spring Band	3.13	2.15	2.64	2.23	1.45	1.84
CRU	1.5	Spring Band	3.36	2.22	2.79	1.71	1.55	1.63
SuperU	1	Spring Broadcast	3.19	2.05	2.62	2.05	1.63	1.84
AgrotainPlus	1	Spring Dribbled	2.92	2.11	2.52	1.87	1.66	1.76
Urea-UAN	1	Split-Early	3.15	2.13	2.64	1.96	1.62	1.79
Urea-UAN	1	Split-Late	3.03	2.00	2.51	2.04	1.56	1.80
		Mean	3.11	2.10	2.60	1.94	1.49	1.72
MSE			0.0891	0.0746	0.0598	0.1646	0.1574	0.1401
Contrasts								
Fall urea vs fall CRU			ns	ns	ns	ns	0.0063	0.0017
Spring urea vs fall urea			ns	0.0389	0.0348	ns	0.0001	0.0001
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			0.0010	ns	0.0025	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns
Spring urea vs late split			0.0102	ns	0.0022	ns	ns	ns
CRU vs SuperU			ns	ns		ns	ns	ns
CRU vs Agrotain			ns	ns	ns	0.0234	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns

Harvest Index

Harvest index (HI) is calculated as grain yield/(grain yield + straw yield) and provides an indication of how efficiently the crop converted the total biomass that it produced over the growing season into grain.

At the Brandon location, the lower slope position had a higher HI than the upper slope position with early seeding, but not with late seeding (Table 7 and Table 8). As grain yield was similar at the two slope positions with the early seeding date, this indicates that a higher total biomass was produced on the upper slope position at the early seeding date, but that the biomass was not converted to grain yield as effectively as on the lower slope position. The hot, dry conditions during grain fill may have resulted in greater moisture stress in the early seeded, upper slope position, restricting conversion of biomass to grain.

At the Phillips location, harvest index was lower with the late-seeded crop on the lower slope than with the other slope-seeding date combinations (Table 7 and Table 9). On the lower slope position, the late seeding date produced relatively high biomass, but did not convert the biomass effectively to grain yield. The early seeded lower slop position had both high biomass and high grain production, while the upper slope positions had low biomass and low grain production, all of which indicate that transformation of available biomass to grain was not restricted in these slope-seeding date combinations.

Table 7: ANOVA table for effects of treatment, area and date on harvest index at two locations

At the Brandon site, application of N reduced HI, but there was generally no significant effect of fertilizer source or management (Table 8). Nitrogen application often reduces HI, because the extra biomass produced by the nitrogen is not all translocated to the grain. At the Phillips location, there was much less reduction in HI with nitrogen application than at the Brandon location. There was no effect of nitrogen source or management on HI at the upper slope position, where dry conditions restricted both biomass production and grain yield. However, at the lower slope position with late seeding, HI was low with fall-banded urea as compared to spring-banded urea or fall-banded CRU, indicating that the loss of nitrogen from the fall-banded urea had a greater impact on reducing grain yield than on reducing biomass production. HI also was lower with the spring-applied CRU than with the spring-applied urea or the early split application. The grain yields with all of these treatments were relatively similar, indicating that the higher total biomass produced by the CRU was not converted as effectively to grain as in the other two treatments.

	Brandon			Phillips		
Effect	DF	F Value	Pr > F	DF	F Value	Pr > F
treat	12	2.36	0.0084	12	1.68	0.076
area	1	55.59	<.0001	1	225.84	<.0001
area*treat	12	0.77	0.6814	12	0.99	0.4657
date	1	41.39	<.0001	1	95.63	<.0001
date*treat	12	0.8	0.6449	12	0.82	0.6273
area*date	1	43.11	<.0001	1	110.56	<.0001
area*date*treat	12	0.5	0.9124	12	1.71	0.0692

Table 8: Effect of nitrogen source, rate and timing on harvest index on upper and lower slope positions, with early and late seeding dates – Brandon 2007

			Lower			Upper		
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean
Control	0	Control	43.7	41.8	42.8	37.1	47.3	42.2
Urea	1	Fall Band	39.7	42.6	41.1	34.1	41.8	37.9
CRU	1	Fall Band	38.6	41.0	39.8	29.0	39.9	34.4
Urea	0.5	Spring Band	41.8	40.9	41.4	35.8	38.6	37.2
Urea	1	Spring Band	42.2	39.2	40.7	31.4	39.2	35.3
Urea	1.5	Spring Band	37.8	38.1	37.9	32.3	39.2	35.7
CRU	0.5	Spring Band	39.9	41.9	40.9	33.8	39.8	36.8
CRU	1	Spring Band	39.3	39.4	39.3	31.9	38.6	35.2
CRU	1.5	Spring Band	39.9	40.0	39.9	35.0	38.9	36.9
SuperU	1	Spring Broadcast	42.2	41.1	41.7	34.0	36.9	35.5
AgrotainPlus	1	Spring Dribbled	39.5	38.1	38.8	32.8	39.5	36.1
Urea-UAN	1	Split-Early	40.3	40.9	40.6	30.6	38.4	34.5
Urea-UAN	1	Split-Late	40.2	39.2	39.7	34.0	40.2	37.1
		Mean	40.4	40.3	40.4	33.2	39.9	36.5
MSE			1.5886	1.0061	0.9267	2.2805	1.9296	1.5149
Contrasts								
Fall urea vs fall CRU			ns	ns	ns	ns	ns	ns
Spring urea vs fall urea			ns	0.0230	ns	ns	ns	ns
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	ns	ns
CRU vs SuperU			ns	ns	ns	ns	ns	ns
CRU vs Agrotain			ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns

Table 9: Effect of nitrogen source, rate and timing on harvest index on upper and lower slope positions, with early and late seeding dates – Phillips 2007

			Lower			Upper		
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean
Control	0	Control	43.7	34.9	39.3	46.9	46.0	46.5
Urea	1	Fall Band	42.9	30.1	36.5	42.9	44.7	43.8
CRU	1	Fall Band	41.7	35.4	38.5	43.2	41.7	42.4
Urea	0.5	Spring Band	44.2	34.7	39.4	47.2	46.1	46.6
Urea	1	Spring Band	43.1	37.0	40.0	42.5	45.2	43.8
Urea	1.5	Spring Band	40.3	33.1	36.7	43.1	44.5	43.8
CRU	0.5	Spring Band	43.6	35.4	39.5	44.1	45.7	44.9
CRU	1	Spring Band	40.8	34.5	37.7	44.6	44.5	44.5
CRU	1.5	Spring Band	43.5	32.9	38.2	41.2	47.1	44.2
SuperU	1	Spring Broadcast	43.6	34.2	38.9	44.7	41.9	43.3
AgrotainPlus	1	Spring Dribbled	40.8	35.2	38.0	45.7	44.5	45.1
Urea-UAN	1	Split-Early	43.0	36.7	39.8	44.0	43.6	43.8
Urea-UAN	1	Split-Late	41.5	35.4	38.5	45.3	43.7	44.5
		Mean	42.5	34.6	38.5	44.3	44.6	44.4
MSE			1.4479	1.5967	1.3223	1.4509	1.4761	1.0349
Contrasts								
Fall urea vs fall CRU			ns	0.0007	ns	ns	ns	ns
Spring urea vs fall urea			ns	0.0001	0.0014	ns	ns	ns
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	0.0305	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	ns	ns
CRU vs SuperU			ns	ns	ns	ns	ns	ns
CRU vs Agrotain			ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	0.0478	ns	ns	ns

Data to Come

Readings were taken on each plot with the SPAD meter and the GreenSeeker as indicators of nitrogen sufficiency. However, these data have not yet been analysed. Tissue samples are awaiting chemical analysis for nitrogen concentration and grain samples for protein content. Impact of seeding date and slope position on soil moisture, soil and air temperature and yield production and response to nitrogen management must still be assessed.

Summary
Field studies were conducted on upper and lower slope positions on two contrasting soil types using early and late seeding dates to evaluate the response of hard red spring wheat to several enhanced efficiency nitrogen fertilizers and nitrogen management practices under varying environmental conditions.

Yields on the poorly drained location were higher on the upper than lower slope position. On the well-drained site, yields were higher on the lower slope position, where moisture supply was better than on the drought-prone upper slope position. Yields at both sites were higher with early than late seeding, with the effect being greater on the lower slope position.

Use of controlled release urea tended to improve grain yield and biomass production with fall applied fertilizer if nitrogen supply was low and the uncoated urea experience nitrogen losses occurred from the fall to the spring. Surface dribble-banded and split applications of nitrogen tended to be less effective than in-soil band applications in promoting grain yield. With spring-applied nitrogen, grain yield was generally little affected by use of the enhanced efficiency fertilizers. Late season drought and heat stress may have reduced the responsiveness to nitrogen fertilizers by restricting the ability of the crop to convert biomass to grain.

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