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.

Efficiency of urea nitrogen use may also be improved 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 (results included in following report – Moulin, Grant and Tremblay - Nutrient Management Study: Analysis of Spectral Data and Residual Soil Properties 2007)

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 in early and late May, three weeks apart. 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-band during the seeding operation. Recommended N rate was based on soil testing and a moderate target yield. In 2008, the rate of application was 50 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 $p<0.05$.

2008 Results

The 2008 growing season began with relatively dry conditions, but it turned wet and cool relatively early in the season. June through August were wetter and cooler than average. Growing conditions were relatively good, with crop yields being high.

Stand Density

Crop emergence was good due to ample moisture after seeding (data not presented). Crop emergence was not affected by fertilizer treatments, indicating no damage or benefit from the various fertilizer sources. Stand was higher with early than late seeding and on upper than lower slope positions at the Brandon site. There was an interaction between seeding date and slope position, with a larger benefit in stand density due to seeding date occurring on the upper slope position (263 vs 183 plants m^{-2}) than on the lower slope position (235 vs 180 plants m^{-2}). At the Phillips site, stand was also higher with early than late seeding, but was higher on the lower than upper slope position. An interaction also occurred at the Phillips site, with the benefit of early seeding on stand density occurring on the lower (262 vs 211 plants m^{-2}) but not the upper slope position (150 vs 157 plants m^{-2}). The Brandon site is a poorly-drained heavy textured location. 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 at heading was assessed by harvesting two-one meter lengths of row, drying at 60C then weighing. There were no interactions among main effects for biomass yield at heading at either location. Biomass yield at heading was affected by slope and treatment at both locations Table 1 to 3). At the Brandon location, biomass yield at heading was higher at the upper slope position than the lower slope position and higher with early as compared to late seeding (Table 1Table 2). On this heavy-textured silty clay soil, early season growth may have been improved on the better-drained upper slope position. Early seeding is generally an advantage for spring wheat production in Manitoba, as it allows a longer growing season, conserves moisture and avoids head stress during flowering. At the Phillips site, yield was higher on the lower than upper slope position, presumably due to the greater moisture supply at the lower slope on this clay loam soil (Table 2 and 3).

Table 1: 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 2008

			Lower			Upper			
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean	Mean
Control	0	Control	6.64	4.19	5.41	7.06	4.35	5.70	5.56
Urea	1	Fall Band	6.33	4.30	5.32	7.74	5.44	6.59	5.95
CRU	1	Fall Band	6.57	4.37	5.47	7.36	4.58	5.97	5.72
Urea	0.5	Spring Band	6.31	4.37	5.34	6.80	4.51	5.66	5.50
Urea	1	Spring Band	6.31	4.52	5.42	6.19	4.66	5.43	5.42
Urea	1.5	Spring Band	6.43	4.90	5.67	6.99	5.46	6.22	5.95
CRU	0.5	Spring Band	6.05	4.44	5.24	7.04	4.11	5.58	5.41
CRU	1	Spring Band	7.06	4.88	5.97	6.94	5.27	6.11	6.04
CRU	1.5	Spring Band	6.45	5.10	5.77	6.31	5.04	5.67	5.72
SuperU	1	Spring Broadcast	6.21	4.85	5.53	6.38	4.29	5.33	5.43
Agrotain	1	Spring Dribbled	6.54	4.77	5.66	6.78	4.80	5.79	5.72
Urea-UAN	1	Split-Early	5.20	4.47	4.83	6.14	4.10	5.12	4.98
Urea-UAN	1	Split-Late	6.22	3.63	4.93	6.01	4.30	5.15	5.04
		Mean	6.33	4.52	5.43	6.75	4.69	5.72	5.57
MSE			0.366	0.256	0.410	0.506	0.302	0.486	0.187
Contrasts									
Control vs spring N			ns	ns	ns	ns	ns	ns	ns
Fall urea vs fall CRU			ns	ns	ns	ns	0.0424	ns	ns
Spring urea vs fall urea			ns	ns	ns	0.0366	ns	ns	0.0427
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns	0.0192
Spring urea vs Super U			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns	ns
Spring urea vs early split			0.0243	ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	0.0182	ns	ns	ns	ns	ns
CRU vs SuperU			ns	ns	ns	ns	0.0208	ns	0.0210
CRU vs Agrotain			ns	ns	ns	ns	ns	ns	ns
CRU vs early split			0.0004	ns	ns	ns	0.0068	ns	0.0001

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 - Phillips 2008

			Lower			Upper			
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean	Mean
Control	0	Control	4.02	4.31	4.16	2.76	3.00	2.88	3.52
Urea	1	Fall Band	4.94	4.75	4.84	4.49	4.10	4.29	4.57
CRU	1	Fall Band	4.52	4.50	4.51	3.62	3.66	3.64	4.08
Urea	0.5	Spring Band	4.52	4.26	4.39	3.35	3.54	3.45	3.92
Urea	1	Spring Band	4.47	4.30	4.38	3.94	3.81	3.88	4.13
Urea	1.5	Spring Band	4.40	5.15	4.77	4.37	3.58	3.98	4.37
CRU	0.5	Spring Band	4.16	4.40	4.28	2.93	3.67	3.30	3.79
CRU	1	Spring Band	4.68	4.41	4.55	3.55	3.80	3.67	4.11
CRU	1.5	Spring Band	4.80	4.97	4.89	3.71	3.70	3.71	4.30
SuperU	1	Spring Broadcast	4.51	4.98	4.75	3.76	4.15	3.95	4.35
Agrotain	1	Spring Dribbled	4.65	4.73	4.69	4.01	3.59	3.80	4.25
Urea-UAN	1	Split-Early	4.37	4.20	4.28	3.15	3.48	3.32	3.80
Urea-UAN	1	Split-Late	4.34	4.21	4.28	3.20	3.32	3.26	3.77
		Mean	4.49	4.55	4.52	3.60	3.65	3.62	4.07
	MSE		0.303	0.205	0.189	0.366	0.364	0.290	0.199
Contrasts									
Control vs spring N			ns	ns	0.0470	0.0102	ns	0.0014	0.0003
Fall urea vs fall CRU			ns	ns	ns	0.0426	ns	0.0356	0.0152
Spring urea vs fall urea			ns	ns	ns	ns	ns	ns	0.0308
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	0.0241	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	ns	0.0451	ns
CRU vs SuperU			ns	ns	ns	ns	ns	ns	ns
CRU vs Agrotain			ns	ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns	ns

Grain Yield

Grain yields at both locations were higher than average due to the adequate moisture and relatively cool growing conditions. At the Brandon site, the upper slope position produced lower grain yield than the lower slope positions (Tables 3 and 5). The results with grain yield were the inverse of the results for biomass yield at harvest and may reflect the benefits of greater moisture at the lower slope position during later growth and grain filling.

Table 3: ANOVA table for effects of treatment, slope and date on grain yield at two locations

	Brandon			Phillips		
Effect	DF	F Value	Pr > F	DF	F Value	Pr > F
treat	12	1.43	ns	12	3.24	0.0004
slope	1	110.4	<.0001	1	144.38	<.0001
slope*treat	12	0.82	ns	12	0.63	ns
date	1	203.08	<.0001	1	42.38	<.0001
date*treat	12	0.89	ns	12	1.03	ns
slope*date	1	0.56	ns	1	0.77	ns
slope*date*treat	12	0.31	ns	12	0.68	ns

Similarly, at the Phillips site, grain yield was higher on the lower slope position than the upper slope position. Moisture conservation and higher soil organic matter associated with the lower slope position on this clay loam soil may have contributed to the higher yield potential. At both locations, grain yield was higher with early as compared to late seeding, but there were no interactions among seeding date, site position and treatment. Presumably, the early seeded crop had a greater yield potential than the later seeded crop, due to the longer growing season, greater moisture availably and reduced heat stress during anthesis.

Grain yield was not increased by N application at the Brandon site (Table 4). Yields were slightly depressed with the fall-applied CRU and with the SuperU, but the reasons for this are unclear.

Grain yield was consistently increased with N application at the Phillips site at all positions and with all seeding dates (Table 5). However, fertilizer source and management practices had no significant effect on N response. In spite of the high yield and the low nitrate test on this soil, averaging 34 kg/ha on the upper slope and 35 kg/ha on the lower slope position, yields did not increase beyond the first 25 kg N ha^{-1} application rate. This is substantially lower than the 70-100 kg ha^{-1} N application rate that would be recommended based on the available soil nitrate.

Table 4: Effect of nitrogen source, rate and timing on wheat grain yield (bu acre^{-1}) on upper and lower slope positions, with early and late seeding dates – Brandon 2008

			Lower			Upper			
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean	Mean
Control	0	Control	58.0	46.8	52.5	51.4	43.7	47.6	50.0
Urea	1	Fall Band	58.3	47.0	52.6	50.0	42.2	46.1	49.4
CRU	1	Fall Band	52.3	45.6	48.9	49.7	39.5	44.6	46.8
Urea	0.5	Spring Band	60.4	45.6	52.9	54.4	42.2	48.3	50.7
Urea	1	Spring Band	58.6	48.5	53.5	53.1	41.2	47.1	50.3
Urea	1.5	Spring Band	58.4	50.8	54.7	50.0	42.5	46.2	50.4
CRU	0.5	Spring Band	59.8	49.8	54.7	48.6	42.8	45.6	50.3
CRU	1	Spring Band	61.7	48.6	55.2	53.5	39.4	46.5	50.8
CRU	1.5	Spring Band	57.1	44.8	51.0	51.0	38.1	44.6	47.7
SuperU	1	Spring Broadcast	54.3	47.4	50.8	45.8	38.4	42.1	46.4
Agrotain	1	Spring Dribbled	60.4	49.2	54.9	44.2	39.7	41.9	48.3
Urea-UAN	1	Split-Early	56.6	48.0	52.3	49.7	40.4	45.0	48.6
Urea-UAN	1	Split-Late	61.1	47.6	54.3	52.8	40.7	46.8	50.6
		Mean	58.3	47.7	52.9	50.3	40.9	45.6	49.2
	MSE		3.3	1.9	2.9	3.4	1.8	2.6	1.6
Contrasts									
Control vs spring N			ns	ns	ns	ns	ns	ns	ns
Fall urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall urea			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns	0.0498
Spring urea vs CRU - 0.5			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns	0.0317
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	ns	ns	ns
CRU vs SuperU			ns	ns	ns	ns	ns	ns	0.0150
CRU vs Agrotain			ns	ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns	ns

The ½ rate of CRU produced lower yields than the ½ rate of urea with early seeding on the lower slope position. Early seeding on the lower slope produced the highest grain yield and would have the highest N demand. It may be that the CRU at the ½ rate did not provide enough N early in the season to support the N demand in this position. Overall, the CRU at the 1.5x rate produced the numerically highest yield, but this was not significantly different from the other fertilizer sources.

Table 5: Effect of nitrogen source, rate and timing on wheat grain yield (bu/acre^{-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	Mean
Control	0	Control	44.6	41.8	43.3	29.9	32.1	31.1	37.2
Urea	1	Fall Band	51.9	47.3	49.5	45.6	36.9	41.3	45.3
CRU	1	Fall Band	54.0	46.5	50.3	40.7	36.6	38.7	44.5
Urea	0.5	Spring Band	52.2	45.2	48.8	37.3	39.3	38.2	43.4
Urea	1	Spring Band	50.8	45.6	48.3	40.9	34.2	37.5	42.8
Urea	1.5	Spring Band	52.3	44.2	48.2	51.9	35.7	43.9	45.9
CRU	0.5	Spring Band	47.6	45.2	46.4	40.0	38.2	39.1	42.7
CRU	1	Spring Band	52.3	45.2	48.8	42.8	40.7	41.8	45.2
CRU	1.5	Spring Band	54.7	50.0	52.3	45.8	39.8	42.8	47.4
SuperU	1	Spring Broadcast	53.1	47.6	50.3	43.0	38.1	40.4	45.3
Agrotain	1	Spring Dribbled	51.9	46.7	49.2	39.4	36.3	37.8	43.4
Urea-UAN	1	Split-Early	52.3	46.4	49.4	42.5	36.1	39.4	44.3
Urea-UAN	1	Split-Late	53.8	46.2	50.0	42.2	41.3	41.8	45.8
		Mean	51.6	45.9	48.8	41.6	37.3	39.5	44.2
	MSE		1.4	1.4	1.5	4.6	3.6	3.6	1.9
Contrasts									
Control vs spring N			0.0001	0.0015	0.0001	0.0009	0.0475	0.0003	0.0001
Fall urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall urea			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			0.0258	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	ns	ns	ns
CRU vs SuperU			ns	ns	ns	ns	ns	ns	ns
CRU vs Agrotain			ns	ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns	ns

Protein Content

Protein content was high at both locations, even in the untreated control (Table 6 to Table 8). Protein content was affected by treatment and seeding date at both sites, and also by slope and a slope x date interaction at the Brandon site.

At both locations, protein content was higher with late than early seeding. Early seeding provides higher grain yield and lower stress during grain filling, generally resulting in lower protein content. At the Brandon site, protein content was higher on the upper than lower slope position. The lower slope position had higher grain yield (Table 4) and therefore protein may have been deceased due to dilution. There was also an interaction between slope and date on the Brandon site, with a larger difference between early and late seeding occurring on the lower slope position.

Table 6: ANOVA table for effects of treatment, slope and date on protein content at two locations

	Brandon			Phillips		
Effect	DF	F Value	Pr > F	DF	F Value	Pr > F
treat	12	4.5	<.0001	12	6.71	<.0001
slope	1	322.39	<.0001	1	0	ns
slope*treat	12	1.13	ns	12	0.41	ns
date	1	59.94	<.0001	1	58.44	<.0001
date*treat	12	1.17	ns	12	0.71	ns
slope*date	1	14.35	0.0002	1	0.01	ns
slope*date*treat	12	0.39	ns	12	0.66	ns

Nitrogen application increased protein content at both sites. At the Brandon site, on the lower slope position, protein content was higher with fall CRU than with fall urea, indicating that the later release of N from the CRU may have preserved N and increased protein content. Similarly, on the upper slope position, protein content was higher with the ½ rate of CRU than the ½ rate of urea, again indicating a benefit to protein content from the later release of N from the CRU.

Table 7: Effect of nitrogen source, rate and timing on protein content 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	Mean
Control	0	Control	15.2	16.3	15.7	16.0	16.6	16.3	16.0
Urea	1	Fall Band	15.5	16.2	15.9	16.9	17.0	17.0	16.4
CRU	1	Fall Band	16.2	16.5	16.4	17.0	17.0	17.0	16.7
Urea	0.5	Spring Band	15.7	16.1	15.9	16.5	16.6	16.6	16.2
Urea	1	Spring Band	16.1	16.3	16.2	16.8	17.0	16.9	16.5
Urea	1.5	Spring Band	15.9	16.5	16.2	16.9	17.0	17.0	16.6
CRU	0.5	Spring Band	15.7	16.2	15.9	16.9	17.0	16.9	16.4
CRU	1	Spring Band	15.9	16.2	16.0	16.7	17.2	16.9	16.5
CRU	1.5	Spring Band	16.0	16.5	16.2	17.0	17.1	17.1	16.6
SuperU	1	Spring Broadcast	15.9	16.3	16.1	17.1	17.2	17.2	16.6
Agrotain	1	Spring Dribbled	15.8	16.2	16.0	17.1	17.0	17.0	16.5
Urea-UAN	1	Split-Early	15.6	16.4	16.0	16.8	17.0	16.9	16.4
Urea-UAN	1	Split-Late	15.9	16.4	16.1	16.6	16.9	16.7	16.4
		Mean	15.8	16.3	16.0	16.8	17.0	16.9	16.4
	MSE		0.241	0.085	0.164	0.202	0.107	0.127	0.090
Contrasts									
Control vs spring N			0.0088	ns	0.0410	0.0001	0.0004	0.0001	0.0001
Fall urea vs fall CRU			0.0440	0.0067	0.0289	ns	ns	ns	0.0254
Spring urea vs fall urea			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall CRU			ns	0.0199	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	ns	ns	ns	0.0160	0.0239	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	ns	ns	ns
CRU vs SuperU			ns	ns	ns	ns	ns	ns	ns
CRU vs Agrotain			ns	ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns	ns

Table 8: Effect of nitrogen source, rate and timing on protein content on upper and lower slope positions, with early and late seeding dates – Phillips 2008

			Lower			Upper			
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean	Mean
Control	0	Control	13.3	14.6	14.0	14.1	15.0	14.5	14.2
Urea	1	Fall Band	15.1	16.2	15.6	14.0	16.5	15.2	15.4
CRU	1	Fall Band	15.6	16.2	15.9	15.1	16.0	15.5	15.7
Urea	0.5	Spring Band	14.7	15.3	15.0	14.8	16.0	15.4	15.2
Urea	1	Spring Band	15.3	15.8	15.5	15.2	15.7	15.5	15.5
Urea	1.5	Spring Band	16.4	16.7	16.5	16.1	17.1	16.6	16.5
CRU	0.5	Spring Band	14.0	16.1	15.0	14.7	15.7	15.2	15.1
CRU	1	Spring Band	15.4	16.6	16.0	15.3	16.2	15.7	15.9
CRU	1.5	Spring Band	16.2	16.7	16.5	15.8	16.7	16.3	16.4
SuperU	1	Spring Broadcast	15.4	16.3	15.8	15.6	16.1	15.8	15.8
Agrotain	1	Spring Dribbled	14.9	16.0	15.5	15.2	16.1	15.6	15.6
Urea-UAN	1	Split-Early	15.1	16.5	15.8	15.6	16.0	15.8	15.8
Urea-UAN	1	Split-Late	15.7	15.9	15.8	15.2	16.2	15.7	15.7
		Mean	15.2	16.1	15.6	15.1	16.1	15.6	15.6
	MSE		0.291	0.262	0.271	0.338	0.445	0.444	0.231
Contrasts									
Control vs spring N			0.0001	0.0001	0.0001	ns	0.0122	0.0054	0.0001
Fall urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall urea			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	0.0469	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	0.0293	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	ns	ns	ns
CRU vs SuperU			ns	ns	ns	ns	ns	ns	ns
CRU vs Agrotain			ns	ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns	ns

At the Phillips site, protein was somewhat lower than at the Brandon site. Protein was increased by N application, but there were few differences among the various fertilizer treatments. Protein content was highest when the N application rate was increased to 1.5 times the base rate of application. On the lower slope position with late application, the CRU at the ½ and full rate of application gave higher protein content than the urea at the same rates, but the effect did not occur at the other slope-seeding date combinations.

Nitrogen Accumulation in the Grain

Nitrogen accumulation in the grain was calculated by multiplying grain yield by N concentration. Nitrogen accumulation in the grain at both sites was higher on the lower than upper slope position, reflecting the higher yield potential (Table 9 to 11). Similarly, N accumulation in the grain was higher with early than late seeding. No interactions occurred among seeding date, slope and N management. ON the Brandon site, treatment had no significant effect on N accumulation in the grain. The N supply on this silty clay soil was very high and N applications were unnecessary to optimise grain yield. Nitrogen accumulation was lower with SuperU than in the other treatments, but the reason for this is obscure.

Table 9: ANOVA table for effects of treatment, slope and date on protein content at two locations

	Brandon			Phillips		
Effect	DF	F Value	Pr > F	DF	F Value	Pr > F
treat	12	1.27	ns	12	6.99	<.0001
slope	1	57.02	<.0001	1	128.24	<.0001
slope*treat	12	0.76	ns	12	0.53	ns
date	1	187.42	<.0001	1	9.19	0.0029
date*treat	12	1.07	ns	12	1.34	ns
slope*date	1	0.26	ns	1	0.26	ns
slope*date*treat	12	0.3	ns	12	0.62	ns

On the Phillips site, N accumulation in the grain was increased substantially by N application, but there was little difference among the treatments. Accumulation was lower with the ½ rate of CRU on the high-yielding lower slope position with early seeding, possibly reflecting a constraint on yield due to slow early-season release at the cut rate. The late split application of N on the upper slope position with late seeding produced higher N accumulation than the spring urea treatment. Under the relatively moist conditions that occurred during this growing season, the late N application may have encouraged some extra late season N uptake.

Table 10: Effect of nitrogen source, rate and timing on protein content on upper and lower slope positions, with early and late seeding dates – Brandon 2008

			Lower			Upper			
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean	Mean
Control	0	Control	103.8	89.9	96.9	97.1	85.5	91.3	94.1
Urea	1	Fall Band	106.6	89.9	98.3	99.6	84.5	92.1	95.2
CRU	1	Fall Band	100.0	88.9	94.4	99.4	79.2	89.3	91.9
Urea	0.5	Spring Band	111.3	86.8	99.0	106.0	82.6	94.3	96.7
Urea	1	Spring Band	110.7	93.0	101.8	105.0	82.5	93.7	97.8
Urea	1.5	Spring Band	109.2	98.8	104.0	99.5	85.3	92.4	98.2
CRU	0.5	Spring Band	110.5	95.3	102.9	96.4	85.6	91.0	96.9
CRU	1	Spring Band	115.3	93.2	104.2	105.4	79.8	92.6	98.4
CRU	1.5	Spring Band	107.4	87.1	97.3	102.4	77.1	89.7	93.5
SuperU	1	Spring Broadcast	101.7	90.9	96.3	92.1	77.7	84.9	90.6
Agrotain	1	Spring Dribbled	112.0	94.4	103.2	88.5	79.7	84.1	93.6
Urea-UAN	1	Split-Early	104.4	92.7	98.5	98.4	81.1	89.8	94.2
Urea-UAN	1	Split-Late	114.1	92.0	103.0	102.8	81.4	92.1	97.6
		Mean	108.2	91.8	100.0	99.4	81.7	90.6	95.3
	MSE		5.74	3.59	4.82	5.92	3.20	4.69	2.75
Contrasts									
Control vs spring N			ns	ns	ns	ns	ns	ns	ns
Fall urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall urea			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns	0.0248
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	ns	ns	ns
CRU vs SuperU			ns	ns	ns	ns	ns	ns	0.0150
CRU vs Agrotain			ns	ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns	ns

Table 11: Effect of nitrogen source, rate and timing on protein content on upper and lower slope positions, with early and late seeding dates – Phillips 2008

			Lower			Upper			
Source	Rate	Timing	Early	Late	Mean	Early	Late	Mean	Mean
Control	0	Control	70.0	72.1	71.1	50.2	56.8	53.5	62.3
Urea	1	Fall Band	92.1	90.2	91.2	75.2	72.0	73.6	82.4
CRU	1	Fall Band	99.1	89.0	94.0	71.8	68.9	70.4	82.2
Urea	0.5	Spring Band	90.6	81.8	86.2	65.7	73.6	69.7	77.9
Urea	1	Spring Band	91.5	85.2	88.3	72.9	63.3	68.1	78.2
Urea	1.5	Spring Band	100.9	86.6	93.8	98.8	71.7	85.2	89.5
CRU	0.5	Spring Band	78.4	85.5	81.9	69.6	71.2	70.4	76.2
CRU	1	Spring Band	94.8	88.3	91.5	77.4	77.7	77.6	84.5
CRU	1.5	Spring Band	104.8	99.0	101.9	84.7	78.3	81.5	91.7
SuperU	1	Spring Broadcast	96.5	91.1	93.8	79.9	72.3	76.1	84.9
Agrotain	1	Spring Dribbled	91.5	88.0	89.8	70.4	69.0	69.7	79.8
Urea-UAN	1	Split-Early	93.0	90.1	91.5	78.3	67.9	73.1	82.3
Urea-UAN	1	Split-Late	99.5	86.6	93.1	75.5	78.4	76.9	85.0
		Mean	92.5	87.2	89.9	74.7	70.9	72.8	81.3
	MSE		3.24	2.43	2.46	8.69	6.84	6.46	3.57
Contrasts									
Control vs spring N			0.0001	0.0001	0.0001	0.0013	0.0074	0.0001	0.0001
Fall urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall urea			ns	ns	ns	ns	ns	ns	ns
Spring urea vs fall CRU			ns	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 0.5			0.0099	ns	ns	ns	ns	ns	ns
Spring urea vs CRU - 1.0			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Super U			ns	ns	ns	ns	ns	ns	ns
Spring urea vs Agrotain Plus			ns	ns	ns	ns	ns	ns	ns
Spring urea vs early split			ns	ns	ns	ns	ns	ns	ns
Spring urea vs late split			ns	ns	ns	ns	0.0483	ns	ns
CRU vs SuperU			ns	ns	ns	ns	ns	ns	ns
CRU vs Agrotain			ns	ns	ns	ns	ns	ns	ns
CRU vs early split			ns	ns	ns	ns	ns	ns	ns

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.

Crop emergence was not affected by fertilizer management, but was higher with early than late seeding. On the heavier textured soil, biomass yield at heading was higher on the well-drained upper slope position than the more poorly drained lower slope position. On the clay loam soil, the effect was reversed, with the higher moisture conditions on the lower slope position promoting higher yield. Final grain yield was higher on the lower- than upper slope positions on both sites, due to the extra available moisture associated with the lower slope positions during grain fill. Grain yield was higher at both positions with early than late seeding, due to the longer growing season, greater moisture availably and reduced heat stress during anthesis. Conversely, protein content was higher with late than early seeding at both locations and higher on the upper slope position at the Brandon site. These differences are likely related to differences in crop yield, as protein content commonly increase as crop yield decreases. Nitrogen accumulation in the grain at both sites was higher on the lower than upper slope position. Similarly, N accumulation was higher with early than late seeding. Differences in N accumulation reflected the higher crop yield on the lower slope positions and with early seeding.

In spite of the high grain yields and low soil nitrate levels, crop response to N fertilization was relatively low. Biomass yield was increased on the Phillips site by N application but there were no differences among the various N sources, when spring applied. Fall application led to the highest biomass yield indicating little loss of N over the winter. Grain yield was also increased by N application at the Phillips site, but fertilizer source and management had no significant effect on response. The nitrogen response was much lower than would be expected with the low soil nitrate level and high crop yield at this site. Nitrogen applications increased protein content at both sites. High protein content at both locations was an indication that mineralization may have provided a high N supply late in the growing season. Use of the CRU increased protein content in some slope-seeding date comparisons at both sites, indicting that the late release of N from the CRU may have enhanced protein production.

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