WINTER WHEAT RESPONSE TO ENCHANCED EFFICIENCY FERTILIZERS IN THE CANADIAN PRAIRIES

J.L. Owens[1], Z. Wang[1], X. Hao[1], L.M. Hall[2], K. Coles[3], C. Holzapfel[4] , E. Rahmani[1], R. Karimi[1] and B.L. Beres[1]*
[1] Agriculture and Agri-Food Canada, Lethbridge Research and Development Centre, 5403 1st Avenue South Lethbridge, Alberta, Canada, T1J 4B1; [2] University of Alberta Department of Agricultural, Food, and Nutritional Science, 410 Ag/Forestry Building, Edmonton, Alberta, Canada, T6G 2P5 (retired); [3] Farming Smarter, 211034 Hwy 512, Lethbridge County, Alberta, Canada, T1J 5N9; [4] Indian Head Agricultural Research Foundation, #1 Government Road. Indian Head, Saskatchewan, Canada. S0G 2K0;
*Corresponding email: brian.beres@canada.ca

ABSTRACT

Optimal nitrogen (N) management can improve agronomic efficiency, and increase winter wheat (*Triticum aestivum* L.) grain yield and protein content. Two experiments were conducted to measure the responses of winter wheat to enhanced efficiency N fertilizers and timing/placements across the Canadian Prairies. Experiment 1 consisted of uncoated urea, urea+nitrification inhibitor (urea+eNtrench®), urea+urease and nitrification inhibitors (SuperU®), and polymer-coated urea (Environmentally Smart Nitrogen®, ESN®). Nitrogen fertilizers were either all side-banded at planting, 30% side-banded at planting + 70% broadcast in-crop in late-fall, or 30% side-banded at planting + 70% broadcast in-crop in early-spring. Experiment 2 compared uncoated urea, urea ammonium nitrate, UAN+nitrification inhibitor (UAN+eNtrench®), UAN+urease inhibitor (UAN+Agrotain Ultra®), UAN+urease and nitrification inhibitors (UAN+Agrotain Plus®), and a 50%-50% mix of ESN® and urea (ESN®/urea). All N sources were 50% side-banded at planting and 50% broadcast in-crop in early-spring. SuperU® and UAN+Agrotain Ultra® split-applied in early-spring produced superior grain yield and N utilization over all other N sources either all applied at planting, split-applied in late-fall or in early-spring. All N sources produced 6.6-9.4% higher grain protein content than the controls, in particular for SuperU®, ESN® and UAN+Agrotain® split-applied in early-spring. The results suggest that split applications of enhanced efficiency N fertilizers is efficient for winter wheat grain yield and protein optimization particularly when the fertilizer includes urease inhibitor or urease and nitrification inhibitors and the majority of N is applied in early-spring.

INTRODUCTION

Winter wheat (*Triticum aestivum* L.) sustainably requires more N supply to maintain high grain yield and protein levels than spring wheat because of its long duration of the vegetative growth stage. However, more N supply has adverse impact on environment due to excessive N will result in significant ammonium emission, denitrification, N leaching and runoff. In addition, winter wheat production includes a period of vegetative dormancy that is characterized by low N requirements during the winter time. The dormant vegetative period and low N requirements will increase the risk of N loss. Optimized N rate, timing and placement or usage of slow/controlled-release fertilizers would be effective strategies to reduce the adverse impact of N on environment. Enhanced efficiency fertilizers (EEF) have coatings that slowly release N, or include additives in their formulation that temporarily reduce urease activity or nitrification rates in soil (AAPECO 2013), and therefore can slow down urea hydrolysis and nitrification process and subsequently synchronize with crop demand. Split N-application is commonly used to harmonize winter wheat N supply with crop demand. Beres et al. (2018) reported that N split-applied at planting and in the spring was most efficient for winter wheat grain yield and protein optimization when combined with an enhanced efficiency urea product under a high-yielding environment.

The objectives of this research are to investigate how fertilizer best management practices, nitrification inhibitors, urease inhibitors, and controlled-release N impact crop N use in dryland winter wheat production systems in the Canadian Prairies.

MATERIALS AND METHODS

Two experiments were conducted at locations representing major dryland agroecosystems across the Canadian Prairies, i.e. Lethbridge, AB, Falher, AB, Indian Head, SK, and Brandon, MB, from 2013 to 2017 with a new site established at each location every year. Besides one dryland site, Lethbridge location also includes an irrigated site. Sites were previously planted with canola (*Brassica napus* L.) except for the Brandon, MB, location in 2013-2014 in Experiment 1, where barley (*Hordeum vulgare*) was previously cropped. A randomized complete block design with four replicates was used for both experiments. Soil nutrient availability were obtained at each site before planting. The N rates were determined based on 80% of the recommended rates targeting a yield of 80 bu ac^{-1}. AC Flourish, a CWRW milling quality variety of winter wheat was used for both experiments.

The treatments in experiment 1 consisted of a factorial arrangement of 14 N management with different N sources and application time/placements. The N sources included: uncoated urea (46-0-0; referred as urea thereafter), urea+nitrification inhibitor (urea+eNtrench®), urea+urease and nitrification inhibitors (SuperU®), and polymer-coated urea (Environmentally Smart Nitrogen®, ESN®). Nitrogen fertilizers were either all side-banded at planting, 30% side-banded at planting + 70% broadcast in-crop in late-fall, or 30% side-banded at planting + 70% broadcast in-crop in early-spring. The N management treatments also included two zero-N controls (one with phosphorus, potassium and sulphur fertilizers applied at the recommended rates based on soil test results; and one with phosphorus only at the recommended rate).

Six N management treatments with different N sources and application timing/placements were used in experiment 2. The N sources included: 1) urea, 2) urea ammonium nitrate (UAN; 28-0-0); 3) UAN+nitrification inhibitor (UAN+eNtrench®), 4) UAN+urease inhibitor (UAN+Agrotain Ultra®), 5) UAN+urease and nitrification inhibitors (UAN+Agrotain Plus®), and 6) ESN® applied at planting + urea applied in-crop. All N were 50% applied at planting (side- or mid-row-banded) and 50% applied in-crop at Feekes 4. The 7th N management treatment is zero-N control (with phosphorus, potassium and sulphur fertilizers applied at the recommended rates based on soil test results).

Herbicide was applied at each site 24-48 hours prior to seeding and in-crop when the average weed growth was the 3-5 leaf stage around mid-October and in spring. Winter wheat was seeded with a ConservaPak™ air drill configured with knife openers spaced 9 or 12 inch apart. The crop was sown at a rate of 45 seeds ft^{-2}, with a target plant density of 34 plants ft^{-2}. Plots were harvested with a plot combine. Grain yield was calculated and corrected to 13.5% moisture. A 4 lb sub-sample was retained to characterize whole grain protein concentration using near infrared reflectance spectroscopy technology (Foss Decater GrainSpec, Foss Food Technology Inc., Eden Prairie, MN).

Three adjacent 2-feet row subsections were harvested in each plot near physiological maturity for straw and grain N determination. Straw and grain N concentration were determined by the Kjeldahl procedure (AACC International 2018). Straw N content (lb ac^{-1}) was calculated by multiplying the %N by the straw biomass (lb ac^{-1}, corrected to 0% relative humidity). Grain N content (lb ac^{-1}) was calculated by multiplying the %N by the grain biomass (lb ac^{-1}, corrected to 0% relative humidity). Total N uptake (lb ac^{-1}) represents the N in aboveground biomass and is the sum of straw N and grain N. Apparent crop recovery efficiency (RE) is the N uptake increase (lb) per lb N applied, which was calculated by the equation below (Fixen et al. 2015):

$$RE = \frac{NF - NC}{NR}$$

where NF (lb N ac^{-1}) is total N uptake in a N fertilized treatment, NC (lb N ac^{-1}) is total N uptake of the control, and NR is N application rate (lb N ac^{-1}). Agronomic efficiency (AE) represents the yield increase (lb) per lb N fertilizer applied, and was calculated by the equation below (Fixen et al. 2015):

$$AE = \frac{Y - Y_0}{NR}$$

where Y is grain yield (lb ac^{-1}) in a N fertilized treatment, Y_0 is the grain yield (lb ac^{-1}) of the control, and NR is N application rate (lb N ac^{-1}).

Data analysis was performed using the SAS platform (Littell et al. 2007; SAS Institute 2011). Homogeneity of error variance was tested using the PROC UNIVARIATE procedure and any outlier observations were removed. Data were analyzed using a two-factor MIXED model and a one-factor MIXED model, respectively, for Experiment 1 and Experiment 2. Nitrogen sources, placements, and N source by placement interactions were treated as fixed effects, and site (combinations of years and locations) and site by treatment (combinations of site by N source and placement for Experiment 1 and site by N source in Experiment 2) were treated as random effects. Effects were considered significant if $p \leq 0.05$.

RESULTS AND DISCUSSION

A notable influence of N source and placement on winter wheat grain yield, protein content and grain N uptake was observed in experiment 1 (Tables 1 and 2). Yields were highest when all N was banded at planting and lowest when N was split-applied in late-fall. Our results in Experiment 1 were in agreement with Adams et al. (2018) and McKenzie et al. (2010) who reported that all N banded at planting produced the highest winter wheat grain yield and grain protein. In this study, banding all N at planting increased grain N by 4.9% relative to a split application in late-fall ($p<0.05$). This may be an indication that banding all N at planting provided plant health benefits resulting in improved abiotic resistance and less winterkill (Beres et al. 2018).

Table 1. Mean responses of yield and protein related variables and agronomic performance to N source and timing/placements in Experiment 1 conducted in MB, SK, and AB, Canada, from 2013 to 2017

Treatment	Grain yield Bu ac^{-1}	Protein content %	Grain-N lb N ac^{-1}	Total N uptake lb N ac^{-1}	RE[†] lb lb^{-1}	AE[‡] lb lb^{-1}
N Source						
Control PKS[§]	50.6	10.6	72.0	88.4	0.0	-0.7
Control P	43.6	10.0	57.4	83.0	0.0	0.0
ESN®	63.3	11.3	92.5	122.7	0.2	4.1
Urea+eNtrench®	64.7	11.1	93.3	124.5	0.2	4.5
SuperU®	65.7	11.3	96.4	129.3	0.2	4.8
Urea	64.5	11.2	93.4	124.3	0.2	4.1
LSD 0.05	0.1	1.6	2.8	NS	NS	NS
Placement						
100% banded at planting	66.0	11.3	96.0	129.8	0.3	4.7
30% banded/70% in-crop late-fall	63.3	11.1	91.6	122.2	0.2	3.9
30% banded/70% in-crop early-spring	64.2	11.3	94.1	123.7	0.2	4.5
LSD 0.05	0.1	1.4	2.4	4.9	0.0	0.6
p-values						
Fixed effects						
N source	0.011	0.016	0.014	0.065	0.149	0.123
Placement	<0.001	0.001	<.001	0.002	0.005	0.022
N source × placement	0.039	0.975	0.164	0.299	0.758	0.736
Random effects						
Site	0.002	0.002	0.002	0.018	0.090	0.041
Site × treatment[¶]	<.001	<.001	<.001	<.001	<.001	0.002

[†] RE = recovery efficiency; [‡] AE = agronomic efficiency

[¶] Treatment is combined N source × placement

Significant N source by placement interactions were detected for grain yield. urea+eNtrench® and SuperU® all banded at planting and SuperU® split-applied in early-spring provided the greatest grain yield (Table 2). In the split application regimes, banding small portion of N at planting ensured N availability in soil to support vegetative growth before spring. Nitrogen requirements increase in spring as winter wheat breaks dormancy, actively begins ‘green-up’ and more N need to be allocated to protein production at booting and flowering stages (Knott 2016; Wuest and Cassman 1992). Therefore, winter wheat tend to be benefited from spring applied N. Campbell et al. (1988) and Gan et al. (2000) have reported that the effect of N application on spring and winter wheat grain yield and protein content depends on environmental conditions, primarily moisture and temperature. In this study, most of the precipitation occurred in the spring and summer at all sites. The co-occurrence of available moisture, warm temperature and N split-applied in early-spring promoted relatively higher grain and protein production compared to N split-applied in late-fall.

All N sources produced 5-13% higher grain protein content than the controls. SuperU®, ESN® and urea produced 1-2% more proteins than urea+eNtrench® (Table 1).

Table 2. Mean responses of yield and protein related variables and agronomic performance to N source by timing/placement interactions in Experiment 1 conducted in MB, SK, and AB, Canada, from 2013 to 2017

Timing/placement	N source	Grain yield Bu ac^{-1}	Protein content %	Grain-N lb N ac^{-1}	Total N uptake lb N ac^{-1}	RE† lb lb^{-1}	AE‡ lb lb^{-1}
	Control PKS*	50.6	10.6	72.0	88.4	---	---
	Control P§	43.6	10.0	57.4	83.0	0	-0.69
100% banded at planting	ESN®	65.9	11.4	95.9	129.3	0.24	4.79
	Urea+eNtrench®	66.3	11.1	95.6	129.7	0.25	4.91
	SuperU®	66.3	11.4	97.2	130.6	0.25	4.96
	Urea	64.8	11.3	94.9	127.8	0.25	4.1
30% banded/70% in-crop late-fall	ESN®	63.3	11.2	92.1	121.5	0.18	3.85
	Urea+eNtrench®	63.8	11.0	90.9	122.0	0.2	4.04
	SuperU®	64.5	11.1	94.1	126.2	0.22	4.53
	Urea	62.6	11.0	89.6	118.1	0.16	3.53
30% banded/70% in-crop early-spring	ESN®	61.7	11.4	90.0	116.4	0.18	4.05
	Urea+eNtrench®	64.2	11.2	93.5	121.0	0.2	4.86
	SuperU®	66.3	11.4	98.2	130.3	0.26	5.07
	Urea	65.7	11.3	95.5	125.8	0.22	4.77
LSD 0.05		0.16	*NS*	*NS*	*NS*	*NS*	*NS*

† RE = recovery efficiency; ‡ AE = agronomic efficiency

*Control PKS = phosphorus, potassium and sulphur fertilizers applied at the recommended rates based on soil test results; § Control P = phosphorus only at the recommended rate

On average, banding all N at planting or split-applied in early-spring provided 2% more protein vs. split-applied in late-fall (p<0.05). Previous researches also indicated that inhibiting nitrification may have created N deficient conditions during heading and flowering, which led to lower protein (Brown et al. 2005; Olson and Swallow 1984; Wuest and Cassman 1992). The low protein content with urea+eNtrench® might be its N release was delayed under the wide range of dry climate conditions in this study.

Total N uptake, RE and AE did not differ among N sources but varied by placements (Table 1). All N banded at planting produced significantly greater total N uptake and RE than when N was split-applied. Agronomy efficiency did not differ between all N banded at planting and split-applied in early-spring; but all N banded at planting and split-applied in early-spring provide significant higher AE than split-applied in late-fall. No significant N source by placement interactions were observed in grain-N, total N uptake, RE, and AE (Table 2).

In Experiment 2, grain yields responded to N sources in the order of UAN+Agrotain Ultra® > urea > UAN+Agrotain Plus® > UAN > UAN+eNtrench® > ESN®/urea > control (Table 3). AUN+Agrotain Ultra® produced significantly higher grain yield than UAN+eNtrench® and ESN®/urea, but no difference was observed between AUN+Agrotain Ultra® and other N sources. Total N uptake from all N sources were

Table 3. Mean responses of yield, protein related variables and agronomic performance to N source in Experiment 2 conducted in MB, SK, and AB, Canada, from 2013 to 2017.

Treatment	Grain yield Bu ac^{-1}	Protein content %	Grain-N lb N ac^{-1}	Total N uptake lb N ac^{-1}	RE[†] lb lb^{-1}	AE[‡] lb lb^{-1}
N source						
Control	50.4	10.6	69.5	98.4	0	-0.2
Urea	65.9	11.5	90.5	138.1	0.22	25.1
ESN®/urea[¶]	63.6	11.6	87.6	129.8	0.18	54.5
UAN	65.1	11.6	88.8	142.6	0.24	44.9
UAN+Agrotain Plus®	65.3	11.6	89.8	144.3	0.25	34.9
UAN+Agrotain Ultra®	67.5	11.6	93.2	143.7	0.23	15.7
UAN+eNtrench®	63.8	11.3	86.3	134.9	0.2	64.4
LSD 0.05	0.23	3.0	5.91	20.43	0.09	1.2
p-values						
Fixed effects						
N source	<.001	<.001	<.001	<.001	<.001	<.001
Random effects						
Site	0.004	0.004	0.011	0.054	0.084	0.009
Site × N source	<.001	0.002	<.001	0.004	0.005	<.001

[†] RE = recovery efficiency; [‡] AE = agronomic efficiency

consistently greater than that of the control, with the greatest in UAN+Agrotain Plus®, but no significant difference existed between different N sources (Table 3). Recovery efficiency displayed the same responses to N sources as total N uptake. UAN+Agrotain Ultra®, urea, UAN and UAN+Agrotain Plus® produced greater AE vs. ESN®/urea, UAN+eNtrench® and the control. Agronomic efficiency was 27% and 16% higher ($p < 0.05$) when winter wheat was fertilized with UAN+Agrotain Ultra® compared with ESN®/urea and UAN+eNtrench®, respectively.

In summary, treatments that included a urease inhibitor or urease and nitrification inhibitors, like SuperU®, UAN+Agrotain Ultra® and UAN+Agrotain Plus®, displayed incremental increases in yield and protein relative to other N sources, regardless of application timings and placements. Therefore, including a urease inhibitor in the N fertilizer formulation will improve N uptake and enhance agronomic performance in the winter wheat systems.

REFERENCES

AACC International. 2018. Approved methods of analysis. 11th ed. Method 46-10.01 (ARCHIVED). Crude protein – improved Kjeldahl method. [Online] Available: http://methods.aaccnet.org/summaries/46-10-01.aspx.

AAPECO. 2013. Official publication number 65. Association of American Plant Food Control Officials.

Adams, C. B., Thapa, S. B., Fan, Y. and Park, S. 2018. Agronomic and economic effects of two enhanced-efficiency urea fertilizer technologies on southern Great Plains winter wheat. Agronomy Journal.

Beres, B., Graf, R., Irvine, R., O'Donovan, J., Harker, K., Johnson, E., Brandt, S., Hao, X., Thomas, B. and Turkington, T. 2018. Enhanced nitrogen management strategies for winter wheat production in the Canadian prairies. Canadian Journal of Plant Science 98(3):683-702.

Brown, B., Westcott, M., Christensen, N., Pan, B. and Stark, J. 2005. Nitrogen management for hard wheat protein enhancement. Pacific Northwest Extension publication PNW578. Oregon State University, Corvallis.

Campbell, C., Zentner, R. and Johnson, P. 1988. Effect of crop rotation and fertilization on the quantitative relationship between spring wheat yield and moisture use in southwestern Saskatchewan. Canadian Journal of Soil Science 68(1):1-16.

Fixen, P., Brentrup, F., Bruulsema, T., Garcia, F., Norton, R. and Zingore, S. 2015. Nutrient/fertilizer use efficiency: measurement, current situation and trends. Managing water and fertilizer for sustainable agricultural intensification 270.

Gan, Y. T., Lafond, G. P. and May, W. E. 2000. Grain yield and water use: Relative performance of winter vs. spring cereals in east-central Saskatchewan. Canadian Journal of Plant Science 80:533–541.

Knott, C. 2016. Identifying Wheat Growth Stages. AGR-224 Cooperative Extension Service University of Kentucky College of Agriculture Food and Environment, Lexington, KY.

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D. and Schabenberger, O. 2007. SAS for mixed models, second edition. Journal of Biopharmaceutical Statistics 17:363-365.

McKenzie, R. H., Middleton, A. B., Pfiffner, P. G. and Bremer, E. 2010. Evaluation of polymer-coated urea and urease inhibitor for winter wheat in southern Alberta. Agronomy Journal 102(4):1210-1216.

Olson, R. V. and Swallow, C. W. 1984. Fate of labeled nitrogen fertilizer applied to winter wheat for five years. Soil Science Society of America Journal 48(3):583-586.

SAS Institute. 2011. SAS OnlineDoc®, Version 9.2. SAS Institute, Inc., , Cary, NC. 1176 pp.

Wuest, S. B. and Cassman, K. G. 1992. Fertilizer-nitrogen use efficiency of irrigated wheat: I. Uptake efficiency of preplant versus late-season application. Agronomy Journal 84:682-688.