UPTAKE OF FOLIAR OR SOIL APPLICATION OF ^{15}N-LABELLED UREA SOLUTION AT ANTHESIS AND ITS AFFECT ON WHEAT GRAIN PROTEIN

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ABSTRACT

Late-season application of nitrogen fertilizer is of interest for increasing grain protein concentration in Canadian Western Red Spring wheat. The objective of this study was to determine the relative effectiveness of foliar versus soil application of urea solution fertilizer (^{15}N enriched) at anthesis in increasing grain uptake of fertilizer nitrogen and grain protein content. Urea fertilizer treatments containing the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) and/or the surfactant Agral 90 were included to show any additional effects of fertilizer additives on nitrogen uptake efficiency. Growth chamber studies were conducted in 1997 and 1998 with Pasqua and AC Barrie wheat, respectively. Nitrogen uptake from soil-applied urea ranged from two to five times that of foliar-applied urea, irrespective of fertilizer additions. Recovery of unamended foliar and soil applied urea-N averaged 6% and 10.5% versus 35% and 65% for Pasqua and Barrie, respectively. Best urea-N uptake from foliar application was achieved using the surfactant with urea (23-27%). Fertilizer N recovery was highest for soil-applied urea treated with NBPT (Pasqua: 54% average; Barrie: 69% average). Grain protein content was significantly higher when urea-N was soil-applied than foliar-applied ($P < 0.05$). Results of this study indicate an increase in grain protein content is better attained by late-season soil application of urea-N than late-season foliar application of an equal rate of urea-N.

INTRODUCTION

Implementation of multiple stepwise protein premiums for Canadian Western Red Spring (CWRS) wheat by the Canadian Grain Commission provides incentive for the producer to fertilize for protein. However, nitrogen use efficiency (NUE) is greatly reduced when fertilizing for high protein (Fowler et al. 1990). Single applications of high rates of N fertilizer early in the growing season can increase grain protein concentration, but at the expense of NUE. Excess N is required to ensure availability during the grain filling period and to compensate for the reduced uptake capacity relative to supply at this developmental stage (Fowler et al. 1990). The excess fertilizer N in the soil, beyond what is required for yield, is subject to leaching and denitrification losses before grain filling. However, with incentives like protein premiums, producers may preferentially fertilize for high protein as long as it is cost effective, regardless of low N recoveries.

Timing the supply of N to coincide with periods of rapid uptake and placing N to facilitate plant access and translocation to grain may improve NUEs for protein enhancement

(Strong, 1982 and Morris and Paulsen, 1985). The efficiency of N utilization may be improved and the N requirement reduced with split N application than if all N is applied at seeding (Ayoub et al. 1994 and Strong, 1982). The benefit of supplemental N fertilization at anthesis or during the two following weeks for increasing grain protein is well established (Gooding and Davies 1992; Strong, 1982; Ayoub et al. 1994 and Sarandon and Gianibelli 1992). The nitrogen can be soil applied in granular or liquid form or foliar applied as a spray. However, there is a general discrepancy as to which method of placement; soil or foliar, produces the most consistent protein increases. Soil applied N is absorbed via plant roots and translocated to the grain with rapid uptake under moist soil conditions. Foliar applied N is rapidly absorbed into leaves (Gooding and Davies, 1992) and also by roots. A proportion of the urea spray contacts the soil surface during application or is subsequently washed from the leaves to the soil by rainfall or irrigation (Alkier et al. 1972; Smith et al. 1991; Strong, 1982 and Below et al. 1985). Foliar applied urea-N can be absorbed into leaves within a few days where at least 80% is reportedly then translocated to the grain (Gooding and Davies 1992).

The main path of uptake of foliar applied urea-N; roots or foliage, is difficult to discern unless the N source is traceable and placement is strictly controlled. In a greenhouse study using ^{15}N-enriched urea, where the soil was protected from foliar spray and soil moisture was not limiting, recovery of urea-N in grain was only about 1% (Alkier et al. 1972). Conversely, using ^{15}N-labelled urea with a surfactant, Altman et al. (1983) recovered a mean of 44% of foliar applied N in the grain when urea was “painted” on leaf surfaces. In a field study, foliar applied labelled urea-N was recovered in both wheat grain and soil (Smith et al. 1991).

The use of a surfactant with foliar applications of urea may promote retention of urea on leaf surfaces and thereby improve foliar absorption. Nitrogen recovery from foliar urea application was markedly higher when a surfactant was added than when no surfactant was used (Altman et al. 1983 and Alkier et al. 1972). The use of a urease inhibitor may improve N recovery with soil or foliar urea applications. The urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) delays hydrolysis of liquid and granular urea applied to the soil surface which reduces NH_3 volatilization by promoting downward movement of urea to plant roots for subsequent hydrolysis and plant uptake. As leaf-tip necrosis observed with foliar urea application is often attributed to NH_3 toxicity (Bremner, 1995), use of a urease inhibitor may reduce tissue damage. However, Krogmeier et al. (1989) found that although the urease inhibitor increased the ratio of urea to NH_3 entering the leaf tissue of soybeans, leaf-tip necrosis persisted, indicating accumulation of toxic levels of urea in the leaf.

Growth chamber studies were conducted in 1997 and 1998 to re-examine the recovery of fertilizer N in grain from foliar versus soil urea-N applications at anthesis and the relative contribution of each placement to grain protein content of CWRS wheat. The studies, modelled after Alkier et al. (1972), were modified to incorporate the contribution of the urease inhibitor NBPT and the surfactant Agral 90 to nitrogen uptake and grain protein content under both placements.

MATERIALS AND METHODS

The study was conducted with Pasqua and AC Barrie CWRS wheat in 1997 and 1998, respectively. The soil was collected from the Ap horizon of an Orthic Black Chernozem Sperling silty clay loam (16.4 µg g^{-1} NO_3-N) and Newdale clay loam (15.4 µg g^{-1} NO_3-N) for the 1997 and 1998 study, respectively. Nitrate-nitrogen content was determined on composite soil samples extracted with 2 M KCl and analyzed using a Technicon Autoanalyzer. The soil was air-dried, mixed and passed through a 1cm screen prior to use.

Plastic pots (3L) were filled with 2 kg of soil treated with 6 mg P L^{-1} as KH_2PO_4, 12 mg K L^{-1} as K_2SO_4 and basal treatments of 0, 25, 50 and 75 mg urea-N kg^{-1} soil (0, 20, 39, 59 kg N ha^{-1}) prior to seeding. Chemicals were dissolved in distilled water and uniformly applied to the soil. The P and K solutions were dispensed in 10 ml aliquots and N dispensed in 5, 10 and 15 ml aliquots, respectively, from a 10 g N L^{-1} solution. Prior to planting, each pot was watered to field capacity with distilled water. Field capacity was 25% for the silty clay loam and 28% for the clay loam. Germinated Pasqua and AC Barrie wheat seeds were placed 1.5 cm below the soil surface in rows at a density of 12 and 10 plants per pot and thinned to 8 and 6 plants in 1997 and 1998, respectively, approximately 2 weeks after emergence. Field capacity was maintained by watering every day or second day as required. Pots were arranged as a randomized complete block design with three replicates. Growth chamber environment conditions in 1997 were 70% relative humidity with 16 hr light at 25°C and 8 hr dark at 17°C for the duration of the study. Growth chamber conditions in 1998 were 70% relative humidity with 16 hr light at 25°C and 8 hr dark at 15°C for the study duration.

Foliar and soil ^{15}N-labelled urea solutions of 11.5 µg N g^{-1} soil (9 kg N ha^{-1}) and 25 µg N g^{-1} soil (20 kg N ha^{-1}) were applied at anthesis in 5 ml and 10 ml aliquots in 1997 and 1998, respectively. Percent excess ^{15}N as urea was 2% for soil- and 18% for foliar-applied urea solutions. Soil treatments were urea solution with and without NBPT. Foliar applications were: 1) urea 2) urea + NBPT (0.14% w/w) 3) urea + the surfactant Agral 90 (0.2% v/v) (1998 only) and 4) urea + NBPT + Agral 90 (1998 only). Soil treatments were applied directly to the soil surface with a pipette dispenser and foliar treatments were sprayed on the foliar surfaces using a manual air pump. Prior to secondary fertilization, the soil surface of pots receiving foliar treatments was completely covered with absorbent cotton to a depth of approximately 5 cm to prevent fertilizer contact with soil. Pots were isolated and individually sprayed to avoid cross contamination. The spray was directed in a narrow stream to achieve maximal contact with leaf surfaces. However, solution contact with leaves was not complete as some spray reached the absorbent cotton and the surrounding work area. The cotton was removed the following day for watering purposes. Water applications were dispensed directly to the soil surface to prevent washing any foliar applied fertilizer onto the soil.

Plants were grown to maturity and the grain harvested, weighed, hand threshed and analysed for total grain N concentration and ^{15}N abundance with an automated combustion instrument (Carlo Erba, Milan Italy) interfaced with an Optima VG isotope ratio mass spectrometer. Percent grain protein was calculated from percent N using 5.7 as the conversion factor. Statistical analysis was conducted using the general linear models procedure (SAS Institute, Inc., 1985) and contrast statements.

RESULTS

Percent applied fertilizer N in grain

Result trends were fairly consistent for both the 1997 and 1998 studies, although N recovery in grain was consistently lower, and effect of fertilizer amendments consistently higher, with Pasqua wheat. Air movement in the growth chamber was directed at the top of the canopy and at the chamber floor for Pasqua and Barrie, respectively. Thus, the growing environment for Pasqua may have been more conducive to NH_3 volatilization, which may partially explain the lower overall N recovery and the greater benefit of amendments relative to that observed with Barrie wheat.

Percent recovery of urea-N applied at anthesis in decreasing order was soil + NBPT > soil >> foliar + Agral 90 > foliar + NBPT + Agral 90 > foliar + NBPT $\geq$ foliar (Figures 1 and 2). Increasing the basal application rate from 0 to 50 ppm had little effect on labelled urea-N uptake, indicating a similar capacity of the plants to utilize the late applied fertilizer at both basal rates. Recovery of N was significantly greater with unamended urea-N soil applications than foliar applications (Table 2; P = 0.0001), averaging 36% and 65% versus 6% and 10.5% in 1997 and 1998, respectively.

Use of NBPT with soil applications significantly increased N recovery in 1997 by an average of 55% (Table 2; P = 0.0001), but by only 11% for Barrie and only at the 0 ppm base N rate. Use of NBPT with foliar applications did not significantly improve N recovery although Pasqua grain recovery increased 20-46%. Tissue damage to both cultivars was minimal with no discernable difference between foliar treatments, indicating no pronounced urea or NH_3 toxicity at the urea concentration used. Nitrogen recovery from foliar applications was maximal when the surfactant Agral 90 was added to urea solution, where recovery increased 116-130%. The surfactant may increase retention of urea on the foliar surfaces and reduce NH_3 loss. Nitrogen recovery was increased significantly with the urea + NBPT + Agral 90 treatment but to a lesser extent than with the urea + Agral 90 treatment. This response may be indicative of the benefits of using a surfactant being counteracted by the disadvantage of using a urease inhibitor, namely prolonged persistence of phytotoxic effects (Bremner 1995).

Grain yield and protein

Grain yield and protein content of both wheat cultivars increased as the amount of N added at planting increased from 0 ppm to 75 ppm (Table 1). Anthesis N did not generally increase grain yield although yields were significantly higher when urea was soil-applied to Barrie wheat, indicating the soil-applied N was used for both protein and yield. Grain protein content was significantly increased by addition of N at anthesis. Protein increases were significantly greater when anthesis N was soil-applied (Pasqua: 11-11.7%; Barrie: 10.7-12.2%) than when foliar applied (Pasqua: 10-11.1%; Barrie: 9.3-11.8%) (Tables 1 and 2). Grain protein did not consistently respond positively to urea additives although increases occurred at the 50 ppm base N rate when urea + NBPT was soil applied and urea + Agral 90 was foliar applied. The overall lower protein levels, ranging from 7.2 to 11.7% for Pasqua and 7.3-12.2% for AC Barrie, are indicative of a nitrogen-stressed growing environment.

DISCUSSION

In agreement with previous research, this experiment shows protein content can be increased by anthesis applications of urea-N to soil or foliar surfaces. Overall, results of the 1997 and 1998 growth chamber studies generally indicate: a) addition of N at seeding appears to establish the range of protein increases that can be obtained with supplemental N late in the growing season, and b) application of anthesis N to the soil appears to be a more efficient N management strategy than foliar placement.

Few studies have employed ^{15}N techniques to precisely quantify the amount of urea-N translocated to wheat grain when either foliar or soil applied later in the growing season (Alkier et al. 1972; Altman et al. 1983; Poulton et al. 1990; Powlson et al. 1989; Smith et al. 1991 and Powlson et al. 1987). The range in previous studies is broad; from 0.9% to 64% (Gooding and Davies, 1992) and is reflective of the varying experimental designs. Recovery of fertilizer N in grain was about 1% when soil contact was prevented versus 37-51% recovery with an equivalent broadcast soil application (Alkier et al. 1972). Protein content from soil applications surpassed that of foliar by 1.9 percentage points. Nitrogen recovery in grain averaged 44% when urea plus surfactant solution was brushed directly on leaf surfaces (Altman et al. 1983). In another study, 69% of urea-N foliar applied at Zadoks growth stage 59 was recovered in above ground plant material and 12% in soil (Smith et al. 1991), showing that some foliar urea spray reached the soil surface or was translocated to the roots after absorption into leaves.

Results of this experiment overall compliment findings of other ^{15}N studies. While N recovery from foliar application was substantially higher than that of Alkier et al (1972), soil uptake was similar or greater and protein response was consistent with the different placements. Addition of a surfactant to foliar urea applications greatly improved N recovery, which may have approached recoveries of Altman et al. (1983) if the solution had been directly applied instead of sprayed. Recoveries may have been higher if the soil was not covered so that spray reaching the soil surface could have been accessed by plant roots.

The higher overall N recovery of soil placed urea-N in this experiment compared with recoveries obtained in previous studies indicates plants may be better able to access soil-placed N than foliar-placed N under moist soil conditions. Foliar N application may be more prone to NH_3 volatilization loss as the spray is dilute and covers a large surface area; conditions which promote rapid urea hydrolysis. Soil N applications can be placed in a concentrated band which restricts the rate of urea hydrolysis and therefore NH_3 loss, particularly if a urease inhibitor is also used. As potentially less urea-N is lost as NH_3, and plants can better access N supplied to roots than applied to foliage, soil placement of late-season N may be the more efficient option.

The soil in this experiment was maintained at field capacity. At lower levels of soil moisture, movement of urea to roots and root uptake may be delayed (Strong, 1982 and Fowler et al. 1990), or NH_3 volatilization losses may be high. Under these conditions, management options would be to: a) use NBPT with soil applications of urea as this may reduce NH_3 losses by slowing urea hydrolysis long enough for moisture conditions to improve, b) foliar apply urea with a surfactant as N recoveries are greater than when no wetting agent is used, or c) not apply any supplemental nitrogen. A good practice is to fertilize for yield at seeding and if growing conditions are favourable and it is economical, additional N can be applied at anthesis to increase grain protein content and take advantage of protein premiums.

In agreement with previous research, this experiment shows protein content can be increased by anthesis applications of urea-N to the soil or foliar surfaces. Overall, results of the 1997 and 1998 growth chamber studies generally indicate: a) addition of N at seeding appears to establish the achievable range of protein increases that can be obtained with supplemental N late in the growing season, and b) application of anthesis N to the soil appears to be a more efficient N management strategy than foliar placement or fertilizing for protein at seeding.

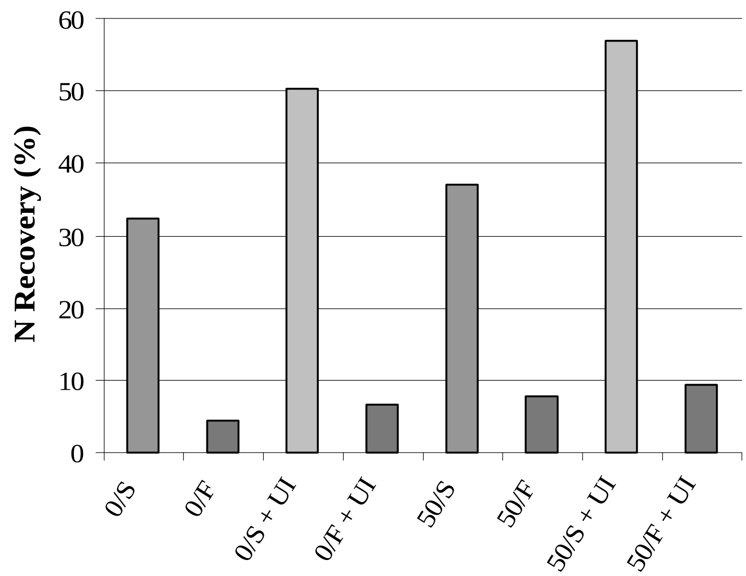

Figure 1. Pasqua wheat grain recovery of urea-N (15N enriched) with NBPT (UI) foliar (F) or soil (S) applied at anthesis under 0 or 50 ppm urea-N rate at planting.

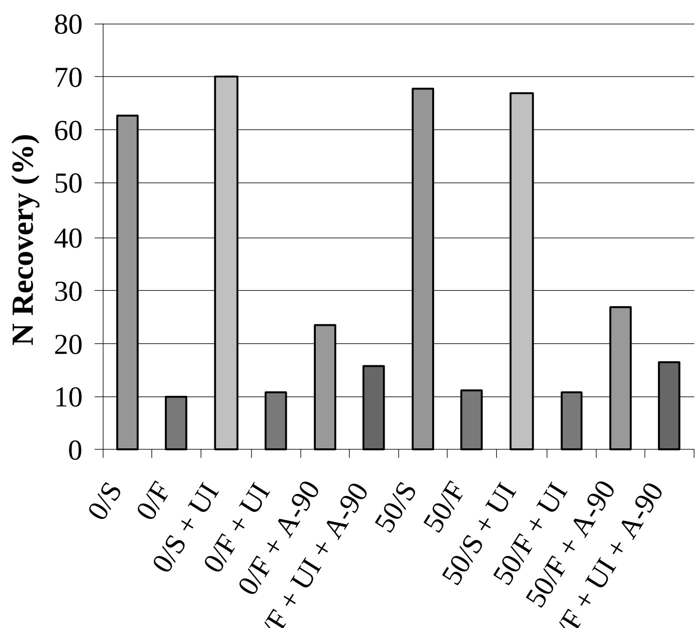

Figure 2. Barrie wheat grain recovery of urea-N (15N enriched) with Agral 90 (A-90) or NBPT (UI) foliar (F) or soil (S) applied at anthesis under 0 or 50 ppm urea-N rate at planting.

Table 1. Grain protein (%) and grain yield (g) for Pasqua and AC Barrie wheat.

Base N[‡]	Cultivar / Anthesis N [†]	Pasqua Grain Protein	Pasqua Grain Yield	AC Barrie Grain Protein	AC Barrie Grain Yield
0	u-soil	11.0	5.4	11.0	9.0
0	u+NBPT-soil	10.8	6.2	10.7	8.6
50	u-soil	11.5	7.9	11.6	11.4
50	u+NBPT-soil	11.7	7.8	12.2	10.7
0	urea-foliar	10.0	5.7	9.3	8.4
0	urea+NBPT-foliar	10.1	5.5	9.6	8.3
50	urea-foliar	10.4	7.0	11.4	10.6
50	urea+NBPT-foliar	11.1	7.9	10.9	10.1
0	urea+Agral 90-foliar	-	-	10.0	8.5
0	urea+Agral 90+NBPT-foliar	-	-	9.8	8.2
50	urea+Agral 90-foliar	-	-	11.8	10.0
50	urea+Agral 90+NBPT-foliar	-	-	11.1	10.2
0		7.2	6.2	7.3	8.1
25		7.5	6.9	7.9	9.6
50		8.5	7.4	8.7	10.2
75		8.6	9.2	9.6	10.5
LSD		1.00	1.44	0.91	0.85

‡ Base N fertilizer (ppm) applied directly prior to planting.

† Anthesis N applied as ^{15}N labelled urea: Pasqua = 11.5 ppm N, Barrie = 25 ppm N.

Table 2. Contrast Pr > F values for N recovery, grain yield and protein for Pasqua and Barrie wheat.

Cultivar	Pasqua			AC Barrie		
Contrast	N Recovery	Grain Yield	Grain Protein	N Recovery	Grain Yield	Grain Protein
0baseNsoil vs 0baseNfoliar	0.0001	ns	0.0211	0.0001	0.0453	0.045
50baseNsoil vs 50baseNfoliar	0.0001	ns	0.0168	0.0001	0.0031	0.0407
0baseNsoil vs 50baseNsoil	ns	ns	0.0004	ns	0.0001	0.0033
0baseNfoliar vs 50baseNfoliar	ns	ns	0.0009	ns	0.0001	0.0001
soil vs soil+NBPT	0.0001	ns	ns	ns	ns	ns
foliar vs foliar+Ag-90	-	-	-	0.0001	ns	ns
foliar vs foliar+NBPT	ns	ns	ns	ns	ns	ns
foliar+Ag-90 vs foliar+NBPT+Ag-90	-	-	-	0.0001	ns	ns
base N vs base N + anthesis N	-	0.0140[†]	0.0001	-	ns	0.0001

† Lower anthesis N rate (11.5 ppm) therefore is not direct comparison of base to anthesis N totals.

ACKNOWLEDGEMENTS

The authors would like to acknowledge funding provided by IMC Global and the Matching Investment Initiative of Agriculture and Agri-Food Canada.

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