POLYMER-COATED UREA APPLICATION RATIOS AND TIMINGS AFFECT WHEAT YIELDS

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Introduction

Several studies have evaluated the impact of N management on winter wheat response (Flowers et al., 2001; Halvorson et al., 2004; McKenzie et al., 2010). Although site conditions can result in variable winter wheat response to N management under the environmental conditions of Missouri, recommended management practices, such as N application timing, fertilizer source, and application rate with winter wheat production are available for conditions in Missouri and include recommendations that producers apply approximately 15% N fertilizer in the fall and 85% in the spring (University of Missouri Extension, 2003). However, the recent introduction of enhanced efficiency fertilizers, such as PCU, for use in agronomic crops may allow more flexibility in application rates and timings for winter wheat production, and therefore, needed to be studied.

Applying N at fall planting up to Feb. can be beneficial for producers because of convenience, cost-effectiveness, lower N fertilizer costs, and favorable soil conditions for application. Optimal N application timings for winter wheat have been reported during periods of greatest plant N demand which is normally during the G25 to G30 growth stages (Zadoks et al., 1974) which corresponds with a Mar. to Apr. application timing (Flowers et al., 2001; Weisz et al., 2001). Nitrogen applied earlier than the G25 and G30 growth stage is more susceptible to adverse weather conditions, which may increase potential N loss, reduce N availability in the spring, and lower wheat yields.

Encasing urea fertilizer prills with a polymer-coat (physical inhibitor), such as with polymer-coated urea fertilizer (PCU) limits the amount of urea available for microbial N transformations after application which may reduce potential environmental N loss compared to traditional dry urea fertilizer (Blaylock et al., 2004, 2005; Motavalli et al., 2008). In order for the urea to be released into the soil environment, water must first dissolve the urea within the prill, and then at a rate dependent on soil moisture and temperature, diffuse out of the polymer coat and into the soil environment (Fujinuma et al., 2009). Polymer-coated urea has been reported to minimize N loss in poorly drained, low lying areas (Noellsch et al., 2009). Surface applications of PCU have also been found to reduce volatilization loss by 60% compared with non-coated urea (NCU) (Rochette et al., 2009).

Use of PCU fertilizer in winter wheat production may be able to minimize yield reductions associated with applications of N before the G25 to G30 growth stage and allow farmers to apply the full rate of N with P and K in the fall. Low soil temperatures in the fall through the winter may greatly reduce the urea-N release from PCU, making N loss from late fall or winter applications of N for winter wheat production negligible compared to spring applications. In a recent wheat study conducted in Missouri, earlier (Nov. to Feb.) application dates resulted in an average yield increase of 4 bu acre^{-1} compared to NCU (Nelson et al., 2008). Blending PCU with NCU may potentially increase overall yields in winter wheat systems by providing a readily available N source and another N source that releases urea-N into the soil over time.

No-till wheat production is common in the Midwest to minimize soil loss on highly erodible soils, such as claypan soils. Adoption of no-till (NT) management is a soil conservation practice and is widely considered to increase soil fertility, yields, and profits by minimizing soil disturbance, erosion, and production costs (Triplett and Dick, 2008). However, NT practices may exacerbate issues of winter wheat plant emergence (Weisz and Bowman, 1999) and N availability (Carefoot et al., 1990) due to impacts on soil conditions (i.e. lower temperature, higher moisture content) and increased N immobilization in surface residues (Halvorson et al., 2004; Kelley and Sweeney, 2007). Dry N fertilizers (i.e. NCU) are typically surface-applied in NT wheat production which can increase the potential for N loss compared to N placement within the soil profile. As well as a greater potential for immobilization of N due to surface residues, which may require increasing the rate of N applied and/or later applications in order to provide adequate amounts of N for wheat uptake to sustain high yielding and quality winter wheat production (Staggenborg et al., 2003).

Site Description and Experimental Design

Field research was initiated in the fall of 2007 and included three consecutive growing seasons in Northeast Missouri's claypan region at the University of Missouri's Greenley Memorial Research Center (40° 1' 17" N 92° 11' 24.9" W) near Novelty, MO on a Kilwinning silt loam with approximately 2 to 5% slope in 2008 and 2009 and on a Putnam silt loam with approximately 0 to 1% slope in 2010. Depth to the claypan at this research station ranged from 12 to 18 in (data not presented). The experimental design included five replications and a non-treated control. Surface broadcasted N fertilizer was applied at two rates (75, and 100 lbs-N $acre^{-1}$), seven application timings (at planting and mid-month in Nov., Dec., Jan., Feb., Mar., and Apr.), and five dry fertilizer source/blends [100% ammonium nitrate (AN), 100% PCU, 100% NCU, 75% PCU:25% NCU, and 50% PCU:50% NCU]. All N fertilizers were broadcast applied to the soil surface using a hand spreader. 'Pioneer 25R56' soft red winter wheat was no-till seeded at 120 lbs $acre^{-1}$ in 7.5-in rows (Great Plains, Assaria, KS).

Results

The percentage release of urea from PCU applied to the soil surface varied considerably due to seasonal variability of rainfall in relation to application timing (Fig. 1). Release of urea fall-applied PCU timings rapidly increased after 15 May 2008, 15 April 2009 and throughout the 2009-2010 season. Rainfall distribution was similar in 2007-2008 and 2008-2009 with majority of the rainfall occurring after Apr.; however, 2009-2010 had an abnormally wet fall (2009) which probably accounted for a greater percentage of urea-N released from PCU fertilizers applied in the fall and early winter. Urea release by 15 June with an Oct. application was approximately 10 to 35% greater ($P < 0.05$) than Feb. to Apr. applications in 2007-2008 and 2009-2010. In 2008-2009, an Oct. application had approximately 15 to 65% greater urea release than all other application timings. Applications in Oct. released less than 10% urea after one month in 2007-2008 and 2008-2009, while 45% of the urea released in 2009-2010 was likely due to higher fall rainfall during that period. Another possibility for the differences in observed release could be due to the effects of variation in the composition or handling of the PCU since the PCU came directly from Agrium (Alberta, Canada) in 2008 and 2009 and in 2010 was from a local retail supplier. Midseason N applications in Feb. averaged 64% release of urea-N which was similar to that released in Nov. and Jan. in 2007-2008, Nov. to Jan. in 2008-2009, and only Jan. in 2009-2010. Significant variation in urea released from PCU applied in Feb. or earlier between seasons was probably due to variation in weather among seasons. Applications of PCU in Mar. to June averaged 54% or less urea released by 15 June. The results of this surface-applied PCU release data indicate that PCU fertilizer N may require the addition of a fast-release fertilizer source when applied after Feb. in order to supply adequate plant available N during high wheat N demand in Mar. and April.

Winter wheat grain yield in 2008 was highest among study seasons, and yield by rate and application timing, ranged from 53 to 84 bu acre. Nitrogen applied in Nov. at 100 lbs acre^{-1} had the highest yields which were 4 to 31 bu acre^{-1} greater ($P < 0.05$) than other combinations of N rate and application timing (Table 1). Nitrogen applications at the G30 growth stage (Apr.), typically the optimal application time (Baethgen and Alley, 1989), at 100 lbs-N acre^{-1} had the next highest yield production which was 2 to 27 bu acre^{-1}greater than all other treatment combination besides 100 lbs-N acre^{-1} applications in Mar. and October. The lowest average yield production for treatments with N applied at 100 lbs-N acre^{-1} occurred with Dec. and Feb. applications. In 2009, wheat grain yield production was less than 2008 and ranged from 32 to 52 bu acre^{-1}. Nitrogen applied in Feb. (75 lbs-N acre^{-1}), Jan. (75 lbs-N acre^{-1}), and Oct. (100 lbs-N acre^{-1}) had 5 to 20 bu acre^{-1} greater yields than N applications in Dec. (100 and 75 lbs-N acre^{-1}) and non-fertilized control plots. Minimal differences in grain yield between application timings may be a function of lower total rainfall which may have reduced the overall potential for N loss and crop production. The 2010 season had 14 in more rain than the 2009 season and 33% above the past decade. This may have increased the potential for N loss resulting in N limitations for crop growth with earlier and lower application rates of N source which resulted in yields similar to 2009 (28 to 51 bu acre^{-1}). Nitrogen applied at 100 lbs-N acre^{-1} in Mar. had 4 to 23 bu acre^{-1} greater yield than all other treatments (N rate x N application timing) besides the Dec. application at 100 lbs-N acre^{-1}. Applications of N from Dec. through Apr. had 3 to 23 bu acre^{-1} greater yields than Oct. and Nov. application timings regardless of N rate, except for Dec. and Feb. applications at 75 lbs acre^{-1}.

In 2008, N treatments of 100% PCU, 75% PCU:25% NCU, and 50% PCU:50% NCU applied at 100 lbs-N acre^{-1} had 3 to 27 bu acre^{-1} greater yields ($P < 0.10$) than all other N rate x fertilizer source treatments (Table 1). When applied at 75 lbs-N acre^{-1}, yield from ammonium nitrate treatments were lower (2 bu acre^{-1}) compared to 100% PCU treatments. Nitrogen applications at 100 lbs-N acre^{-1} found 100% NCU treatments had lower yields (3 to 4 bu acre^{-1}) than 100% PCU, 75% PCU:25% NCU, and 50% PCU:50% NCU treatments presumably due to higher N fertilizer loss. On average, addition of PCU fertilizers in most instances increased winter wheat yield production, but may require high N application rates to overcome slower release of urea-N available for microbial N transformations. These results are similar to a no-till study conducted in Southern Alberta, which found PCU application had 2.2% greater soft red winter wheat yields when broadcast-applied compared to NCU application (McKenzie et al., 2010). Minimal differences in yield occurred in 2009 due to N rate and fertilizer source. However, treatments of 100% NCU at 75 lbs-N acre^{-1}, 50% PCU:50% NCU at 75 lbs-N acre^{-1}, 100% PCU at 100 lbs-N acre^{-1}, and non-fertilized control plots had lower yields (4 to 20 bu acre^{-1}) compared to 75% PCU:25% NCU at 75 lbs-N acre^{-1} and 50% PCU:50% NCU at 100 lbs-N acre^{-1}. Although the potential for N loss may have been low in 2009, NCU has the greatest potential for gaseous N loss (Rochette et al., 2009) and treatments with high percentage of NCU appeared to have had enough N loss to justify higher application rates of N. Nitrogen treatments of ammonium nitrate, and 75% PCU:25% NCU had no yield differences between N applied at 75 and 100 lbs-N acre^{-1}. Lack of significance between treatments of N rate x N application timing and N rate x N fertilizer source in 2009 may have been a combination of lower overall N loss potential and increased variability in grain yield production. These results paralleled a three year winter wheat study which found N application timing, N rate, and N fertilizer source impacted yields, but found minimal impact during a drier season which they concluded was due to limited N loss potential (McKenzie et al., 2010). In 2010, 100% PCU and AN treatments at 100 lbs-N $acre^{-1}$ had 3 to 20 bu $acre^{-1}$ greater grain yields than all other treatments. Treatments of 100% NCU and 50% PCU:50 % NCU were probably the most vulnerable to N loss and may have led to a reduced availability of N for crop uptake. However, 100% NCU and 50%PCU:50% NCU at 75 lbs-N $acre^{-1}$ had 3 to 7 bu $acre^{-1}$ lower grain yields than the other N source treatments with N applied, except for ammonium nitrate (75 lbs-N $acre^{-1}$), and 75% PCU:25% NCU (75 lbs-N $acre^{-1}$) treatments. These results further support claims that PCU minimized N loss compared to NCU fertilizers in wet soil conditions with high potential for N loss which increased N uptake and yield of corn (*Zea mays* L.) (Noellsch et al., 2009).

Averaging over N rate (0, 75, 100 lbs-N $acre^{-1}$), AN treatments applied in Apr. for the 2008 season had the highest yields (83 bu $acre^{-1}$), which was 3 to 19 bu $acre^{-1}$ greater ($P < 0.10$) than all other N source treatments, excluding Nov. applications of AN, NCU, PCU, 75% PCU:25% NCU, and Apr. applications of NCU (Table 2). Comparing applications from Oct. thru Apr., N fertilizer source treatments either increased yields by 7 to 10 bu $acre^{-1}$ (AN and NCU), decreased yields by 8 bu $acre^{-1}$ (100% PCU), and were similar (75:25% and 50:50% blends of PCU and NCU) over this period. Treatments of 100% PCU in Oct. produced similar yields compared to NCU applications in Mar. and Apr., but had 3 bu $acre^{-1}$ lower yields than Apr. applications of AN. Therefore, a delay in fall application after 15 Nov. was warranted. In 2009, yield differences were again minimal due to lower rainfall, N loss potential, and variability in yield. The highest yield in 2009 was obtained from AN and 75% PCU:25% NCU applications in Feb. and Apr. (56 bu $acre^{-1}$), respectively. In 2010, AN treatments applied in Apr. had the highest average yield (50 bu $acre^{-1}$), but were not significantly different than all N treatments applied in March. For all N source treatments, excluding 100% PCU, yields were increased 7 to 14 bu $acre^{-1}$ from Oct. to April. A delay in PCU application until mid-Nov. increased yield 4 bu $acre^{-1}$ compared to an Oct. application. The trend of increasing yields with Oct. to Apr. applications of PCU:NCU blends ranging from 100% PCU to 100% NCU treatments appeared to be magnified as the percentage of NCU applied increased in N source treatments, due to the greater potential for N loss compared to PCU in extremely wet soil conditions reported in claypan soil (Noellsch et al., 2009). Treatments containing 50, 75, and 100% PCU applied in Oct. had 6 to 15 bu $acre^{-1}$ lower yields than readily available N sources (AN and NCU) applied in Mar. and April, but no difference was observed with 100% PCU from Dec. to March. The release of PCU was faster in 2010 than 2008 or 2009 (Fig. 1). Our results imply that use of PCU minimized yield reductions with fall applications; however, in extremely wet growing seasons, applications timed closer to the G25 and G30 growth stage are potentially more important for fast release N sources in terms of yield and the need to reduce the amount of PCU was demonstrated. Nonetheless, farmers have fertilizer technology options that allow them to target mid-Nov. or spring applications.

Conclusions

Wheat yields increased with N rate (0 to 100 lbs-N $acre^{-1}$), but the amount they increased over these N rates varied across seasons depending on factors, such as the potential for N loss, N fertilizer source, applications timings. Late N applications occurring in Mar. and Apr. averaged relatively higher winter wheat grain yields as expected but were not always significantly greater than Nov. to early winter applications if the potential for N loss was minimal and/or PCU was applied. Polymer-coated urea is a viable N fertilizer source for fall applications, and may even increase grain yields over NCU fertilizers in seasons with high rainfall and N loss potential, especially in years when wet conditions delay spring N applications. This flexibility could reduce the need for typical split N applications for wheat. Potential yield benefits from blending of PCU and NCU fertilizers compared to 100% PCU treatments were the greatest when applied in March or April.

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Table 1. Winter wheat grain yields by N rate and application timing or fertilizer source(s) from the 2007-2008, 2008-2009 and 2009-2010 growing seasons.

		N application timing†							N fertilizer source‡				
									100%	100%	100%	75:25%	50:50%
Year	Rate	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	AN§	NCU	PCU	PCU/NCU	
	lbs acre^{-1}	bu acre^{-1}							bu acre^{-1}				
2007-08	0	53	--	--	--	--	--	--	53	--	--	--	--
	75	73	77	70	72	67	76	76	73	71	75	74	73
	100	79	84	76	78	70	79	80	76	76	79	80	79
	LSD	2							2				
2008-09	0	32	--	--	--	--	--	--	32	--	--	--	--
	75	50	51	45	52	52	48	50	51	48	52	52	46
	100	52	50	47	51	51	49	51	51	50	46	51	52
	LSD	5							3				
2009-10	0	28	--	--	--	--	--	--	28	--	--	--	--
	75	36	37	42	45	42	46	46	42	40	44	42	41
	100	39	42	49	47	48	51	46	47	44	48	45	45
	LSD	3							2				

† Fisher's Least Significant Difference ($P = 0.05$).

‡ Fisher's Least Significant Difference ($P = 0.10$).

§ Abbreviations: AN, ammonium nitrate; NCU, non-coated urea; PCU, polymer-coated urea.

Table 2. Soft red winter wheat grain yields by application timing or fertilizer source from the 2007-2008, 2008-2009 and 2009-2010 growing seasons. Grain yields were averaged over applications of 0, 75, and 100 lbs-N $acre^{-1}$.

Year	N fertilizer source†	Ratio (%)	N application timing						
			Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
			bu $acre^{-1}$						
2007-08	AN	100	74	81	76	71	59	75	83
	NCU	100	73	80	70	72	64	77	81
	PCU	100	80	81	74	80	76	78	72
	PCU/NCU	75:25	77	81	74	79	72	79	76
	PCU/NCU	50:50	77	79	72	72	72	79	80
		LSD (P = 0.10)	3						
2008-09	AN	100	54	54	46	51	56	47	50
	NCU	100	51	47	47	51	52	47	49
	PCU	100	46	49	45	52	48	54	48
	PCU/NCU	75:25	51	51	49	51	49	53	56
	PCU/NCU	50:50	51	51	43	52	52	43	49
		LSD (P = 0.10)	7						
2009-10	AN	100	40	37	48	47	41	50	50
	NCU	100	33	36	42	45	45	47	47
	PCU	100	41	45	47	48	47	50	44
	PCU/NCU	75:25	35	43	47	46	45	48	43
	PCU/NCU	50:50	36	37	43	44	45	47	47
		LSD (P = 0.10)	4						

† Abbreviations: AN, ammonium nitrate; NCU, non-coated urea; PCU, polymer-coated urea..

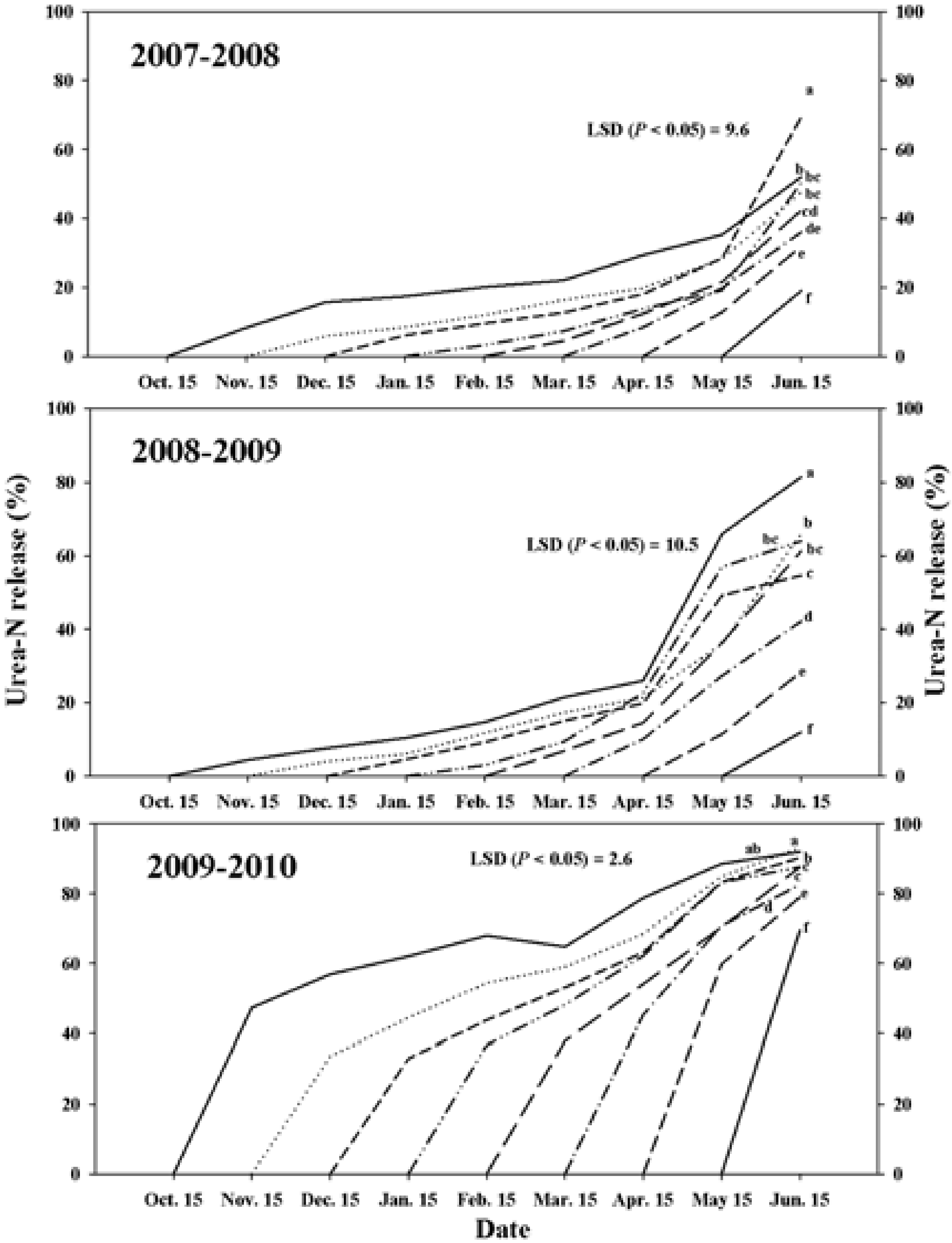

Figure 1. In-field evaluation of the percent urea-N released from PCU fertilizer applied to the soil surface at different application timings from 15 Oct. to 15 May 2008 to 2010. Measurement of the release was conducted using mesh bags and continued each year until 15 June.