POLYMER COATED UREA AND TIME OF APPLICATION FOR CORN PRODUCTION IN MINNESOTA

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ABSTRACT

Managing N for corn (Zea mays L.) production is a key to minimizing N losses. Excessively wet spring conditions resulting from ongoing climate change exacerbate the potential loss of early spring N applications. Also, a shift with less anhydrous ammonia and more urea availability in certain regions calls for an extensive evaluation of other N sources across different soil conditions to update the current N best management practices. The objectives of this research are to evaluate various urea, polymer-coated urea (PCU), and PCU-urea blends and N application timing strategies in corn production and determine the agronomic and economic optimum N rate and grain yield, N use efficiency and indirectly the potential for N loss to the environment, and their cost-benefit relationship. Nitrogen sources and application time were evaluated in a 3-yr study corn study grown in a corn-soybean rotation under irrigation in well to excessively well drained soils at Rosemount and Becker, MN and in dryland conditions in poorly to somewhat poorly drained soils in Waseca and Lamberton, MN. Grain yield, the economic optimum N rate (EONR), net return, and residual inorganic soil N at post-harvest were measured at each site/year. For the dryland soils, grain yield was significantly affected by N source in only 2 of 3 years at Waseca with no differences at Lamberton. However, the use of PCU-Urea blends resulted in lower EONRs than Urea or PCU in dryland soils for the three growing seasons, and PCU had lower EONRs than Urea in 2023 at Lamberton. In irrigated corn, grain yield was significantly affected by N source only in Rosemount 2021. Also, the split application of PCU-Urea blend had lower EONR but not necessarily greater economic net return than Urea in these sandy soils. Drought years, particularly 2021, resulted in greater soil TIN after harvest especially at the highest N rates.

INTRODUCTION

Nitrogen (N) fertilization is essential for corn production, but N loss can diminish environmental health and farmers' profitability. Excessively wet spring conditions resulting from ongoing climate change can exacerbate loss potential of early spring N applications in Minnesota. At the same time, anhydrous ammonia is being rapidly replaced by urea as the major N source, which poses concerns. Because of volatilization issues, urea applications are done early so urea can be incorporated into the soil by tillage before planting. Because urea nitrifies quicker than anhydrous ammonia, this can lead to more N loss potential. Alternatively, in-season application can reduce N loss in wet springs, but driving in wet fields can be logistically impossible. In addition, in-season urea applications add cost and need to be incorporated quickly by rain or irrigation, or a urease inhibitor is needed to mitigate volatilization loss. Irrigating when unnecessary, simply to incorporate fertilizer, results in added cost and increased N loss potential if followed by substantial precipitation. One way to circumvent these issues is to use controlled release fertilizers, such as polymer-coated urea (PCU), or PCU-urea blends in tandem with application timing management. The goals are to evaluate various urea, PCU, and PCU-urea blends and N application timing strategies in corn production across four locations in Minnesota and determine 1) the agronomic and economic optimum N rate and grain yield, 2) N use efficiency and indirectly the potential for N loss to the environment, and 3) their cost-benefit relationship.

MATERIALS AND METHODS

A 3-yr (2021-2023) corn study grown in a corn-soybean rotation was conducted under irrigation in well- to excessively well-drained soils at Rosemount and Becker, MN and in dryland conditions in poorly- to somewhat poorly-drained soils in Waseca and Lamberton, MN.

Each study consisted of five N rates that cover the range of corn grain yield response to nitrogen (below, at, and above optimal). For dryland (non-irrigated) soils, N rate response curves for pre-plant only applications included blend of Urea (46-0-0, N-P-K) and PCU [ESN (44-0-0, N-P-K)] that varied by one-third increments from 100% Urea to 100% PCU (Table 1) with total N rates of 0, 60, 120, 180, and 240 lb N ac^{-1}. In these soils with corn after soybean, corn grain yield is normally optimized around 130 lb N/a. For irrigated soils N rate response curves were developed with various combinations of source and time of application with applications done in three splits with equal amounts of N at V2, V6, and V8/V10 (Table 1) with total N rates of 0, 80, 160, 240, and 320 lb N ac^{-1}. Urea was applied with a urease N inhibitor Agrotain (N-(n-Butyl) thiophosphoric triamide, NBPT) to minimize volatilization losses, but were incorporated by rain or irrigation within 24 hrs. of application. For irrigated soils with corn after soybean, corn grain yield is normally optimized around 180 lb N/a.

Although we are not presenting it here, we also evaluated a set of different N source/N time combinations at a single total rate (120 or 160 lb N ac^{-1} for dryland and irrigated soils, respectively). Timings were pre-plant (PP) or split at PP and at V6 corn stage in dryland soils, and split in various combinations at V2, V6, and V10 corn stage for the irrigated soils.

Table 1. N rates and N sources for dryland and irrigated corn.

Dryland corn (Lamberton- Waseca)		**Irrigated corn (Becker- Rosemount)**	
N rate lb N ac^{-1}	**N source**	**N rate lb N ac^{-1}**	**N source**
0	100% Urea	0	1/3V2(Urea)-1/3V6(Urea)-1/3V10(Urea)
60	1/3 PCU-2/3Urea	80	1/3V2(PCU)-1/3V6(Urea)-1/3V10(Urea)
120	2/3 PCU-1/3 Urea	160	1/3V2(PCU)-1/3V6(PCU)-1/3V10(Urea)
180	100% PCU	240	1/3V2(1U:2PCU)-1/3V6(2U:1PCU)-1/3V10(Urea)
240		320	

Corn yield and grain N content was measured at harvest. Corn economic optimum N rate (EONR) was calculated at a fertilizer to corn price ratio of 0.1 (US$0.50

lb^{-1} N; and \$5.00 bushel^{-1} of corn). Fall 2023 prices were used to calculate net return: Urea US\$0.70 lb^{-1} N fertilizer, ESN \$0.93 lb^{-1} N fertilizer; Corn \$4.7 bushel^{-1}.

After harvest, soil samples were collected from each plot using a 40-mm inside diameter soil core sampler (Giddings Machine Co., Fort Collins, CO) at the 0-12, 12-24, and 24-36-inch depth increments and analyzed for NH_4^+-N and NO_3^--N, and the sum of both was calculated to determine residual soil total inorganic N (TIN).

An in-situ incubation of PCU fertilizer was performed and N release curves were evaluated at 4 sites during each growing season at planting (AP) or V2, V6 and V10 corn development stages. Data presented correspond to the 2021 growing season.

The experimental design was a randomized complete block with four replications. Statistical analysis was performed using the SAS software. Mean differences were consider significant at P=0.05.

Table 2. Mean monthly precipitation (inches for the 30-yr normal and the 2021, 2022, 2023 growing season at each experimental site.

Location	Year	April	May	June	July	Aug.	Sept.	Apr.-Sept. cumulative
					--inches --			
Becker	Normal (1991-2020)	**2.8**	**4.1**	**4.1**	**4.0**	**4.0**	**3.2**	**22.1**
	2021	2.7	3.1	1.3	1.2	3.7	2.8	14.8
	2022	3.3	6.7	2.3	1.9	5.8	2.9	22.9
	2023	5.0	1.1	1.2	3.1	4.2	3.9	18.4
Rosemount	Normal (1991-2020)	**3.0**	**4.4**	**5.1**	**4.4**	**4.6**	**3.4**	**24.9**
	2021	2.0	3.2	1.8	1.3	4.9	2.8	16.0
	2022	3.7	4.1	0.9	2.1	6.3	0.4	17.3
	2023	3.5	2.4	2.2	3.8	1.6	4.4	17.9
Waseca	Normal (1991-2020)	**3.3**	**4.5**	**5.4**	**4.9**	**4.8**	**4.1**	**27.0**
	2021	0.6	2.7	2.0	2.7	4.8	1.9	14.8
	2022	3.8	4.7	4.4	4.6	5.5	0.8	23.7
	2023	3.7	6.5	1.6	1.6	3.3	2.2	18.8
Lamberton	Normal (1961-2020)	**2.8**	**3.5**	**4.0**	**3.7**	**3.2**	**3.2**	**20.5**
	2021	1.4	2.7	0.5	1.2	4.8	5.0	15.6
	2022	3.6	3.9	1.1	1.6	3.0	0.7	13.9
	2023	3.9	7.1	2.9	1.0	2.0	0.6	17.4

RESULTS AND DISCUSSION

Overall, the three growing seasons were dry, ranging from 3.1 to 12.2 inches below normal, except Becker 2022 where precipitation was 0.8 inches above normal (Table 2).

For dryland soils, there was a positive response to N application on grain yield at both locations (Table 3). The current MRTN guidelines indicate 131 lb N ac^{-1} and a range of 118 to 144 lb N ac^{-1} for corn-soybean cropping systems. The EONRs in our study were within or close to the range except for Waseca 2022 and 2023 and Lamberton 2021 where EONRs were higher than the MRTN (Table 3). Across N rate, grain yield was significantly affected by N source in 2 of 3 years at SROC with no differences at SWROC. However, when all the N source/timing were compared at the same N rate (120 lb N ac^{-1}) differences were observed only in 2022 at SROC, and 2021 at SWROC (data not shown).

For irrigated soils, there was a positive response to N application on grain yield at both locations (Table 4). The current MRTN guidelines for irrigated corn indicate 179 lb N ac^{-1} with a range of 162 to 195 lb N ac^{-1} for corn-soybean cropping systems. The EONRs in our study were lower than the MRTN, ranging from 21 to 66 lb N ac^{-1} lower than the MRTN, except Becker 2021 which was 6 lb N ac^{-1} above the MRTN but within the acceptable range. Since the effect of drought could be managed by irrigation, lower EONRs with relatively high yields represent high N use efficiency and likely reflect the fact that N losses were low during these growing seasons. Further, while nitrate concentrations in irrigation water are low for these sites, greater irrigation amounts than normal also contributed to more than normal N application through irrigation than normal, which likely contributed in a small degree to lowering the EONR. Across N rate, grain yield was significantly affected by N source in 1 of 3 years at Rosemount with no differences at Becker. However, when all the N source/timing were compared at the same N rate (160 lb N ac^{-1}) differences were observed in 2022 for SPRF, and 2021 and 2022 for RROC (data not shown).

Across years and N rates, the highest net return was for 1/3PCU PP-2/3Urea in Waseca (Table 5). The use of PCU-Urea blends resulted in lower EONRs than Urea or PCU. At Lamberton, PCU-Urea blends resulted in lower EONRs than Urea however N returns were lower than Urea (Table 5). For irrigated soils, EORNs were lower for the 1/3 PCU-2/3 Urea treatment in 2021, and the Urea+PCU blend in Becker (Table 4). At Rosemount, the EONRs were lower for all treatments with PCU compared to Urea. For both sites, however the overall net return was higher for Urea treatments (Table 6).

Though there were differences due to soil type, in all situations residual soil N at post-harvest was greater when N was applied over the EONR (Fig.1). The 2021 growing season showed greater residual total inorganic N after harvest regardless of N rate especially at Lamberton and Becker. The higher residual N is likely related to substantial drought during the 2021 growing season (Fig. 1).

Overall, N released from in-situ PCU incubations followed similar pattern across sites and time of application (Fig. 2), however dry conditions typically created further delays in the N release, especially at Lamberton where it was dry after the application, unlike Waseca that received precipitation after V10. These release curves showed that early application of PCU will ensure greater N availability and synchronization with crops need compared to late applications.

Summary

For dryland soils, the PCU-Urea blends showed lower EONRs than Urea at most sites/years, but responses were likely smaller in magnitude due to the dry conditions and low potential for N loss.

For irrigated soils, the split application of blends of PCU and Urea had lower EONRs but not necessarily a greater net return than Urea alone.

N release curves showed the importance of early application of PCU fertilizer to maximize N availability for crop uptake.

Drought years, particularly 2021, resulted in greater soil TIN after harvest especially at N rates above the EONR.

Table 3. Corn grain yield for the dryland sites from 2021 to 2023 growing seasons.

	Corn Grain Yield (bu ac^{-1})					
	Waseca			**Lamberton**		
N rate (lb N ac^{-1})	**2021**	**2022**	**2023**	**2021**	**2022**	**2023**
0	110 d	130 d	106 d	92 d	120 c	75 c
60	148 c	183 c	138 c	117 c	158 b	132 b
120	160 b	215 b	160 b	128 b	183 a	161 a
180	164 ab	230 a	179 a	134 b	184 a	159 a
240	168 a	232 a	184 a	144 a	191 a	171 a
EONR (lb N ac^{-1})	132	178	220	194	149	143
Yield$_{EONR}$ (bu ac^{-1})	164	230	183	139	187	164
MRTN (lb N ac^{-1})	131 (118-144)					

Table 4. Corn grain yield for the irrigated sites from 2021 to 2023 growing seasons.

	Corn Grain Yield (bu ac^{-1})					
	Becker			**Rosemount**		
N rate (lb N ac^{-1})	**2021**	**2022**	**2023**	**2021**	**2022**	**2023**
0	117 d	89 c	84 c	155 c	139 d	148 c
80	187 c	193 b	169 b	230 b	199 c	184 b
160	210 b	224 a	192 a	243 a	211 b	189 ab
240	219 ab	231 a	198 a	244 a	219 ab	196 a
320	225 a	224 a	202 a	245 a	225 a	189 ab
EONR (lb N ac^{-1})	185	149	150	123	158	113
Yield$_{EONR}$ (bu ac^{-1})	220	226	197	243	219	190
MRTN (lb N ac^{-1})	179 (162-195)					

Table 5. Economic optimum N rate (EONR, lb N ac^{-1}), grain yield (bu ac^{-1}) at the EONR, and net return for Waseca and Lamberton across N rates and years.

	Waseca			Lamberton		
--Nitrogen Blend--	**EONR**	**Yield**	**Net return**	**EONR**	**Yield**	**Net return**
Preplant	**lb N ac^{-1}**	**bu ac^{-1}**	**\$ ac^{-1}**	**lb N ac^{-1}**	**bu ac^{-1}**	**\$ ac^{-1}**
Urea	181	194	867	201	186	751
1/3 PCU - 2/3 Urea	168	193	868	117	157	714
2/3 PCU - 1/3 Urea	165	192	863	127	159	703
PCU	185	193	838	187	178	696

Prices: Urea 0.54, 1.03, 0.85 $/lbN; **PCU** 0.76, 1.25, 1.07 $/lbN; **Corn** $5.22, 6.64, 4.9$/bu for 2021,2022, and 2023 respectively.

Table 6. Economic optimum N rate (EONR, lb N ac^{-1}), grain yield (bu ac^{-1}) at the EONR, and net return for Becker and Rosemount across N rate and years.

			Becker			Rosemount		
------Nitrogen Blend------			**EONR**	**Yield**	**Net return**	**EONR**	**Yield**	**Net return**
V2	**V6**	**V10**	**lb N ac^{-1}**	**bu ac^{-1}**	**\$ ac^{-1}**	**lb N ac^{-1}**	**bu ac^{-1}**	**\$ ac^{-1}**
1/3-Urea	**1/3-Urea**	**1/3-Urea**	165	217	962	154	222	1010
1/3-PCU	**1/3-Urea**	**1/3-Urea**	141	210	931	149	218	975
1/3-PCU	**1/3-PCU**	**1/3-Urea**	198	220	925	132	214	949
1/3(1Urea:2PCU)	**1/3(2Urea:1PCU)**	**1/3-Urea**	138	211	935	108	217	985

Prices: Urea 0.54, 1.03, 0.85 $/lbN; **PCU** 0.76, 1.25, 1.07 $/lbN; **Corn** $5.22, 6.64, 4.9$/bu for 2021,2022, and 2023 respectively.

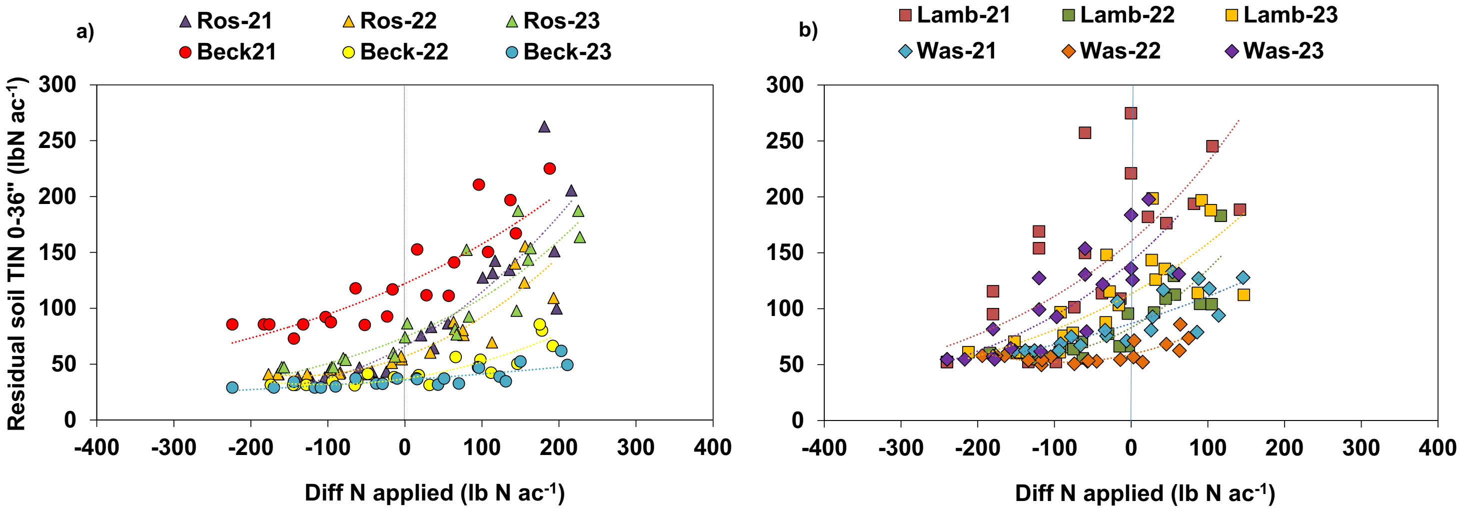

Figure 1. Residual soil Total Inorganic N (TIN) (lb N ac^{-1}) at 0-36 inches soil depth and the difference between N rate and EONR (Diff N applied, lb N ac^{-1}) for Rosemount and Becker (a) (irrigated soils) and Lamberton and Waseca (b) (dryland soils) for 2021, 2022, 2023 growing seasons.

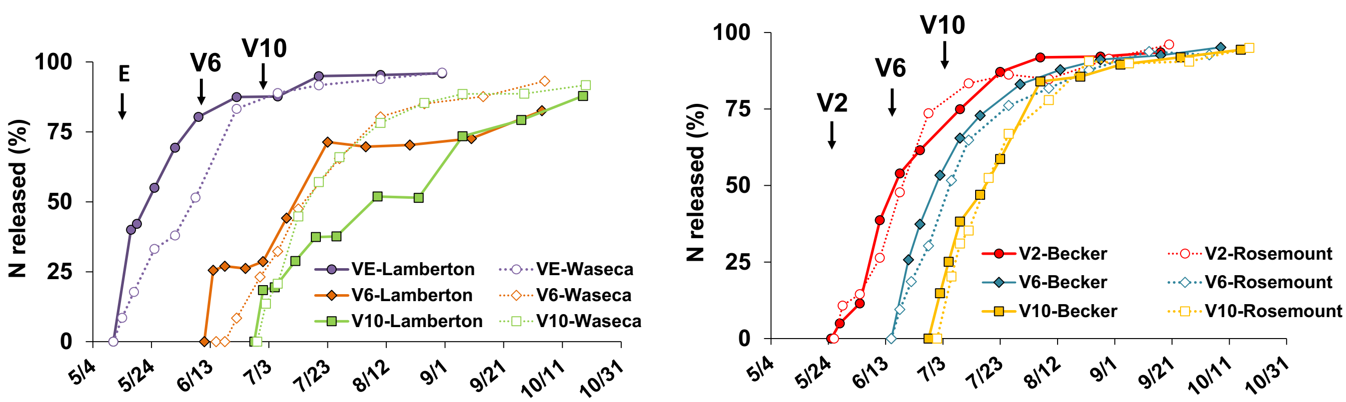

Figure 2. N released curve from PCU fertilizer in fine-textured and sandy soils. 2021 growing season