EVALUATION OF SLOW-RELEASE NITROGEN MATERIALS IN CORN PRODUCTION

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Studies were conducted over a two year period to evaluate two slow release urea nitrogen carriers with regular urea for the production of corn on irrigated Spinks loamy sand. Because nitrogen availability in the soil is quite transient from one season to the next, annual addition of nitrogen is important for maximum corn yields. Many corn producers prefer to apply most of the nitrogen prior to planting corn. Once incorporated into the soil, nitrogen containing materials, such as urea, are converted by microbial activity to the ammonium and then to the nitrate form of nitrogen. In the nitrate form, N is readily taken up by corn roots, but is also subject to loss by leaching and denitrification. Therefore, timing the release of N from urea or other N sources to coincide with need by the corn crop would help minimize the potential for loss. The two slow-release N materials used in this study apparently have different modes of action, but both are designed to gradually release N into the soil solution over time. The objectives of these studies were to determine whether the slow release nitrogen materials can improve corn yields over regular urea when applied at similar rates, or result in the same corn yield with less nitrogen applied, and/or result in a lower nitrate N concentration in the soil and a reduced risk for loss of nitrate.

Research Approach

The site for this study was the Michigan State University Montcalm Research Farm near Entrican, Michigan. The soil is Spinks loamy sand. In 2003, the previous crop was dry edible beans followed by a cereal rye cover crop. In 2004, the previous crop was a corn variety trial. In both years the residual soil N level was relatively low prior to planting. Soil test values were pH 5.9, Bray P1-P 158 & 144 ppm, ammonium acetate extractable K 76 & 80 ppm. After plowing, 180 lb K_20/A was broadcast and incorporated. Two slow release nitrogen materials, ESN (encapsulated urea) and an experimental occluded urea (OUN, impregnated into perlite granules) were evaluated in comparison with regular urea (0-46-0). The three nitrogen carriers were broadcast and incorporated on May 5, 2003 and May 8, 2004. Three nitrogen rates in 2003 and four rates in 2004 (80, 120, 160 and 200 lb N/A) were applied and incorporated prior to planting the corn. The nitrogen treatments and a no N check plot were arranged in a randomized complete block design within each of four replications. Each plot consisted of six – 50 foot rows spaced 2.5 feet apart (i.e., plot size was 15 ft x 50 ft). The corn (DeKalb C44-66) was planted on May 5 and May 8 respectively in the two years at a seeding rate of 32,500 seeds per acre.

Rainfall in 2003 was fairly uniformly distributed, but in 2004 excessive rain fell during May and was generally adequate during June, July and August (Table 1). The corn was irrigated as needed with a linear move overhead irrigation system. In 2003, soil samples were collected to 18 inches during May, August and November and divided into 6 inch increments. In 2004 samples were taken to 36 inches during June, July August and November. In order to monitor changes in the soil nitrate and ammonium N status soil cores were collected in a plastic sleeve with a slide hammer sampler. The cores were refrigerated at 42 F until cut into the depth segments. They were then rapidly dried in a forced air oven set at 140 F. The nitrate and ammonium N concentrations in the soil samples were determined by extraction with 1 *N* KCl; 10 grams soil to 50 ml extract solution shaken for 30 minutes and filtered before analysis with a Lachat rapid-flow spectrophotometer. In collecting the soil samples a dense layer was found to occur in the profile at about 30 inches deep.

Table 1. Rainfall and irrigation on corn plots at MSU Montcalm Research Farm. 2003 and 2004.

	2003		2004	
Month	Rainfall	Irrigation	Rainfall	Irrigation
	- - inches - -		- - inches - -	
May	3.25	0.00	10.80	0.00
June	1.85	0.60	4.07	0.00
July	2.60	1.65	2.25	1.00
August	2.60	1.90	2.42	2.25
September	2.06	0.00	0.44	0.00

Two ceramic cup lysimeters were placed in each check plot and each of the plots receiving 200 lb N per acre (2003 only). The ceramic cup of each lysimeter was centered at a depth of 18 inches. Samples of the soil solution were drawn six times during the growing season; June 5 and 27, July 21, August 19, September 17 and October 24. The nitrate and ammonium N concentrations were determined with a Lachat rapid-flow analyzer. Results were variable so lysimeters were not installed in 2004.

Plant tissue samples were taken at: 1) V4 - whole plant samples, 2) at silking – ear leaf samples, and 3) at grain black layer – stalk segments 8-16 inches above the ground. Grain samples were collected at harvest. The stalk tissue was analyzed for nitrate N concentration. All other collected tissues were analyzed for total N.

In early July, 2004 the corn leaves showed signs of zinc deficiency. The corn plants in all plots were sprayed on July 9 with 0.5 pound of zinc and 2 pounds of manganese per acre. Grain yield was determined by hand harvest of 20 row-feet of each of the two center rows in late October.

Results and Discussion

Available soil nitrate N level was quite low (less than 2 ppm) in the top 12 inches prior to application of fertilizer materials. Ammonium N was less than 1.5 ppm. On June 16, 2003, 39 days after application of the three materials, the soil nitrate and ammonium N levels were significantly increased as the result of the nitrogen applications. In the check plots there was a significant increase in the nitrate-N as the result of mineralization, perhaps from the breakdown of the incorporated rye cover crop. This was equivalent to about 27 lb N/A-18 inches. The nitrate and ammonium N concentrations in the three depths were similar for OUN and Urea (Table 2). Where ESN had been applied the nitrate N concentrations in the 0-6 inch depth were lower than with the other two materials whereas the ammonium N concentrations were higher at both the 120 and 160 lb N/A rates. This indicates that the nitrogen released from ESN was not as readily converted from the ammonium form to the nitrate form. With all materials and at all three rates there appears to have been significant downward movement of nitrogen as indicated by the levels of nitrate in the 12-18 inch depth. This is in agreement with the high nitrate N concentrations in the soil water drawn from the lysimeters set at 18 inches deep. In mid-July the nitrate concentration in the lysimeter water was 10 to12 ppm with all N sources (200 lb N/A) compared to 4 ppm in the control.

Table 2. Nitrate and ammonium N concentrations in soil on June 16, 2003, 39 days after application of nitrogen fertilizers.

N Rate	Soil Depth	Urea		Nitrogen Source OUN		ESN	
lb/A	inches	NO_3-N	*NH_4-N*	NO_3-N	*NH_4-N*	NO_3-N	*NH_4-N*
		- - - - - - - -		- mg N/kg soil -		- - - - - - - -	
0	0–6	10.5	*2.5*				
(Check)	6-12	3.5	*1.6*		$Lsd_{.05}$ =	7.1	*3.1*
	12-18	5.0	*1.7*				
120	0-6	31.4	*3.2*	29.6	*3.0*	19.7	*9.3*
	6-12	8.3	*2.3*	8.0	*2.1*	9.9	*4.1*
	12-18	13.5	*2.2*	8.9	*1.5*	11.1	*5.2*
160	0-6	33.5	*5.6*	36.4	*6.9*	31.2	*10.8*
	6-12	9.1	*2.2*	7.6	*2.3*	6.5	*2.8*
	12-18	9.5	*1.9*	9.0	*1.9*	12.4	*3.0*
200	0-6	34.8	*10.3*	37.4	*6.3*	37.5	*15.1*
	6-12	7.6	*1.9*	8.7	*2.7*	8.3	*3.1*
	12-18	12.1	*2.5*	15.2	*2.8*	14.0	*4.8*

Table 3. Nitrate and ammonium N present in a Spinks sandy loam on June 16, 2003, 39 days after application of regular urea and two slow release urea materials.

Nitrogen Rate	Urea		OUN		ESN	
	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
lb N/A	- - lb/A-18" - -		- - lb/A-18" - -		- - lb/A-18" - -	
120	96	*14*	84	*12*	67	*34*
160	94	*17*	95	*18*	90	*30*
200	97	*26*	110	*21*	108	*41*

In the 0 N control plot there was 34 lb NO_3-N/ A-18" and *10* lb NH_4-N/ A-18".

The amount of nitrogen (nitrate + ammonium) measured in the check plots amounted to 44 lb/A-18 inches (Table 3). The net increase in measured extractable nitrogen for the urea treatments over the control in the top 18 inches of the soil was 66, 67 and 79 lb/A-18", respectively at 120, 160 and 200 lb N/A. For OUN the net increases in extractable N over the control were 52, 69 and 87 lb N/A-18". For ESN the net increases in extractable N over the control were 57, 76 and 105 lb N/A-18". At all three N rates there was significantly more ammonium N present with ESN than with OUN or urea, which accounts for the higher total extracted soil N with ESN. The difference between the net measured amounts of N and the amounts applied may be accounted for by unreleased or unsolubilized N, uptake, leaching or volatilization. At the V4-5 stage when these samples were taken, plant uptake probably accounted for less than 20 lb N/A. With soil moisture levels being more than adequate, it is presumed that most of the N in urea was solubilized and converted to ammonium and nitrate N. Hence, much of the difference with urea is likely due to a combination of volatilization or denitrification and leaching below the 18 inch depth. With the slow release materials, ESN and OUN, there was likely some movement of N below the 18 inch depth, but presumably there was considerable N still unreleased from the fertilizer granules. By August 19 soil nitrate N levels had been decreased significantly by crop uptake (Table 4). Soil in the ESN treated plots had significantly higher nitrate N levels than with the other two materials.

Table 4. Nitrate and ammonium N concentrations in soil on August 19, 2003.

	Soil	Nitrogen Source		
N Rate	Depth	Urea	OUN	ESN
lb/A	Inches	NO_3-N	NO_3-N	NO_3-N
			---- mg N/kg soil ----	
0	0-6	0.96		
(Check)	6-12	0.75	$Lsd_{.05}$ =	2.6
	12-18	0.45		
120	0-6	1.95	2.10	4.80
	6-12	1.90	1.76	3.64
	12-18	1.08	1.63	1.64
160	0-6	3.14	3.34	8.21
	6-12	2.39	2.43	7.00
	12-18	2.45	1.65	3.06
200	0-6	3.94	4.98	8.24
	6-12	4.04	4.79	10.16
	12-18	2.76	2.34	5.35

In 2004, initial nitrate and ammonium N levels in the soil were fairly uniform across the plots and replications. In the top 6 inches of soil the nitrate concentration ranged from 4.0 to 4.6 mg N/kg soil and the ammonium concentration ranged from 1.5 to 1.7 mg N/kg soil. This is equivalent to about a total of 11 lb N/A. The 6 to 12 inch depth contained the equivalent of 7 lb N/A (5 + 2). The 1 to 2 foot and the 2 to 3 foot depths each contained 7 to 8 lb N/A equally distributed between nitrate and ammonium. The nitrate and ammonium N concentrations in soil samples taken on June 15 primarily reflect the effects of the nitrogen rates applied (Table 5) with lesser effects from the materials. This was about five weeks after application. During this time period there was excessive rainfall, about 12.5 inches. This was a severe test on the nitrogen materials. Some nitrogen may have been lost by leaching or denitrification. In general the nitrate N concentration in the top 6 inches reflected the amount of nitrogen applied regardless of material. The data show significant downward movement of nitrate N into the 1 to 2 foot depth with urea and OUN, but little with ESN. This movement was modest at the 80 lb N/A rate and was quite significant with the 120, 160 and 200 lb N/A rates. These data show that even though there was significant downward movement of nitrate most of it remained in the active root zone. A dense layer at 30 inches probably restricted further downward movement. Having an elevated nitrogen concentration in the 12 to 24 inch zone may actually be advantageous when moisture becomes limiting in the surface soil.

Table 5. Nitrate and ammonium N concentrations in soil with depth on June 15, 2004 in relation to four rates of three N fertilizers.

N Rate	Soil Depth	Nitrogen Source: Urea		OUN		ESN	
lb/A	inches	NO_3-N	*NH_4-N*	NO_3-N	*NH_4-N*	NO_3-N	*NH_4-N*
		- - - - - - -		mg N/kg soil		- - - - - - -	
Zero	0 – 6	3.3	*4.2*				
(Check)	6 – 12	4.0	*4.2*		***$Lsd_{.05}$*** =	***12.3***	***2.6***
	12 – 24	2.4	*2.5*				
	24 – 36	2.6	*2.4*				
80	0 – 6	12.2	*3.4*	19.9	*4.2*	14.6	*5.5*
	6 – 12	11.3	*3.3*	15.4	*3.5*	6.3	*3.4*
	12 – 24	5.7	*1.8*	5.7	*2.3*	3.9	*2.0*
	24 – 36	2.9	*2.1*	3.2	*2.9*	3.1	*2.2*
120	0 – 6	19.5	*6.2*	20.0	*3.2*	21.1	*8.7*
	6 – 12	16.9	*4.4*	16.4	*2.3*	8.6	*3.7*
	12 – 24	11.6	*3.5*	9.6	*2.2*	3.8	*3.0*
	24 – 36	3.6	*2.4*	3.7	*2.4*	2.7	*2.1*
160	0 – 6	24.3	*3.9*	23.5	*3.9*	31.1	*12.1*
	6 – 12	24.6	*3.0*	28.5	*3.3*	8.8	*3.5*
	12 – 24	9.8	*3.3*	16.2	*2.4*	5.1	*2.7*
	24 – 36	3.1	*1.9*	4.8	*2.1*	3.2	*2.8*
200	0 – 6	31.9	*4.2*	28.7	*3.9*	30.7	*9.1*
	6 – 12	25.4	*4.0*	21.6	*3.8*	7.3	*3.8*
	12 – 24	11.5	*2.9*	10.8	*2.3*	3.6	*1.9*
	24 – 36	4.4	*2.3*	4.6	*2.6*	2.5	*2.3*

Corn plant biomass at the V4-5 stage was consistently greatest with OUN suggesting these plants were receiving more available nitrogen (Table 6). ESN had the lowest biomass suggesting a lower early nitrogen supply. Chlorophyll readings taken on recently mature leaves on July 6 were very low (35.3) for plants receiving no supplemental N. When nitrogen was applied, readings were similar across materials. With 80 lb N/A applied, the Chlorophyll readings averaged 47.4. For the other three N rates the readings were similar and averaged 48.3, ranging from 48.1 to 48.7.

Table 6. Corn (DeKalb C44-66) biomass on June 15, 2004 in relation to increasing rates of three N fertilizers. Spinks sandy loam. MSU Montcalm Research Farm.

Nitrogen Applied	Urea	OUN	ESN
lb N/acre	- - - -	g / 12 plants -	- - -
0	40 d		
80	71 b	90 a	63 bc
120	70 b	78 ab	68 b
160	65 b	80 ab	68 b
200	71 b	75 ab	57 c

The next set of soil samples were taken 6 weeks later on July 28, 2004 when the corn was silking and tasseling. Nitrogen uptake by the corn crop kept the readily available nitrogen levels relatively low in the soil, except where 200 lb N/A was applied (Data not presented). In all soils there was an increase in the ammonium N concentration from the mineralization of organic materials in the soil. Soil nitrate levels were maintained below 4 ppm in the top 12 inches with the 80 and 120 lb N/A. Applying 160 lb A resulted in 6 to 7 ppm and 200 lb N/A resulted in about 10 ppm. These values were similar among the three materials.

On August 26 the soil nitrate and ammonium levels were relatively low and similar among all materials, except where 200 lb N/A was applied the soil nitrate level in the top 12 inches was 6 to 7 ppm (Data not presented). This reflects heavy nitrogen uptake by the corn plants. By the middle of November the soil nitrate and ammonium N levels were quite low in all treatments and at all depths. With the mild dry fall very little if any leaching would have occurred. The low levels of available nitrogen are most likely the result of crop uptake. These levels were lower than prior to planting in early May (1 to 2 ppm each of nitrate and ammonium N).

Key diagnostic plant tissues that may reflect the nitrogen environment of the plant roots and the status of the plant include: 1) whole plant at V4-5, 2) ear leaf at silking, 3) lower stalk at grain black layer, and 4) corn grain at harvest. In 2003, the total N content of the whole corn plant at V4-5 was similar among all materials and across all rates and did not differ from plants receiving no supplemental fertilizer N (Table 7). The ear leaf N concentration was lower in plants that received no N than those fertilized with the urea materials. There were no significant differences among the materials or the N rates. At grain black layer, the stalk nitrate N concentration was extremely low (25 ppm) in plants receiving no supplemental N. Where 120 lb N/A was applied the stalk nitrate N level with urea averaged 1462 ppm, with OUN 1985 ppm and with ESN 2421 ppm. Research at Purdue University has shown that stalk nitrate values less than 450 mg/kg indicates yield was limited by nitrogen. Between 450 and 2000 mg/kg indicates that adequate nitrogen was available to the crop and yield was not limited by nitrogen supply. Values above 2000 ppm indicate that more nitrogen was available than was necessary to maximize yield. At the 160 lb N/A rate the stalk nitrate value with urea was unchanged, but with the two slow

Table 7. Nitrogen status of corn plants at various stages of growth and corn grain as affected by nitrogen carrier and rate. 2003.

Nitrogen Carrier	Nitrogen Rate	V4 Whole Plant	Ear Leaf	Stalk	Grain
		% N	% N	mg NO_3-N /kg	% N
Check	0	3.57	2.87	25	1.05
Urea	120	3.48	3.31	1462	1.23
OUN	120	3.67	3.39	1985	1.24
ESN	120	3.53	3.50	2421	1.24
Urea	160	3.62	3.53	1402	1.23
OUN	160	3.48	3.35	3077	1.23
ESN	160	3.49	3.77	4230	1.24
Urea	200	3.52	3.42	2288	1.23
OUN	200	3.68	3.24	2826	1.22
ESN	200	3.65	3.22	4233	1.25
$Lsd_{.05}$		ns	0.14	821	0.15

release materials the nitrate N concentrations increased significantly indicating that more nitrogen was being supplied and accumulated than was necessary. Increasing the N rate to 200 lb N/A increased the stalk nitrate N concentration into the excessive range with urea, but with the two slow release materials the already excessively high values did not increase further. This indicates that nitrogen was being used more effectively from OUN and ESN. Both of these materials at 120 lb N/A were as effective in supplying nitrogen to the corn plants as urea was at 200 lb N/A. The grain N, and hence grain protein, content of the grain was increased by nitrogen application, but there were no differences among materials or rates.

In 2004, stalk nitrate levels were significantly affected by nitrogen rate and to a lesser degree by nitrogen material. The stalk nitrate values were near zero at the 80 lb N/A rate and were still well below the critical 450 ppm value with 120 lb N/A applied (Table 8). Interestingly, grain yield was near optimum at this nitrogen rate (Table 9). Applying 160 lb N/A brought the stalk nitrate values into the optimum range, but no further increase in yield occurred, and applying 200 lb N/A resulted in very high values indicating excess nitrogen application. Total N in the ear leaf at silking was very low in corn plants that did not receive supplemental nitrogen. Total N in the grain increased with increasing nitrogen rate, but was not affected by material. Overall, it appears that the nitrate concentration in the lower corn stalk best reflects the nitrogen environment that the plant experiences throughout its growth and development.

Table 8. Nitrogen status of corn plants at various stages of growth and corn grain as affected by nitrogen carrier and rate. 2004.

Nitrogen Carrier	Nitrogen Rate	Ear Leaf	Stalk	Grain
		% N	mg NO_3-N /kg	% N
Check	0	1.46	2	0.82
Urea	80	2.01	2	0.98
OUN	80	2.07	4	0.99
ESN	80	2.44	2	0.92
Urea	120	2.62	263	1.14
OUN	120	2.41	314	1.10
ESN	120	2.81	125	1.04
Urea	160	2.71	1190	1.19
OUN	160	2.87	1363	1.18
ESN	160	2.60	843	1.18
Urea	200	3.09	3670	1.22
OUN	200	2.85	3404	1.24
ESN	200	2.69	3205	1.24
$Lsd_{.05}$		0.73	387	0.18

Grain yield response was in best agreement with the stalk nitrate N data. In 2003, applying 120 lb N/A increased grain yield from 158 bu/A to near 195 bu/A (Table 9). Increasing the N rate to 160 or 200 lb N/A resulted in the same yields, near 195 bu/A, with all three materials. Grain moisture was slightly higher with OUN and Urea applied at 200 lb N/A compared with no N being applied, but there were no significant differences among the N materials and rates. Corn grain test weights were quite low in 2003 in Michigan compared to other years and N rate had little effect. In 2004 test weight was improved by nitrogen application. Grain test weight was lower in grain from the 0 and 80 lb N/A plots than from plots receiving 120 or more lb N/A.

Corn grain yield in 2004 was affected significantly by the amount of nitrogen applied (Table 9). With no additional nitrogen applied, the corn plants were nitrogen deficient throughout most of the growing season and the yield was 82 bushel per acre. Applying 80 lb N/A increased grain yield by 87 bu/A, on average, across the three N materials. Applying 120 lb N/A further increased grain yields (26 bu/A) with no differences in yield occurring among the three nitrogen materials. Maximum grain yield occurred with 160 lb N/A, but it was not statistically greater than with 120 lb N/A. The economic optimum N rate was near 120 lb N/A.

Table 9. Grain yield of corn (Dekalb C44-46) grown on a Spinks loamy sand with three broadcast rates of urea and two slow release urea materials.

Nitrogen Carrier	Rate	Grain Yield[1] 2003	Grain Yield[1] 2004	Moisture 2003	Moisture 2004	Test Weight 2003	Test Weight 2004
	lb N/A	- bu/A -		- - % - -		- lb/bu -	
Check	0	158	82	28.5	28.3	48.4	48.4
Urea	80		167	- -	23.0	- -	50.8
OUN	80		179	- -	24.1	- -	50.1
ESN	80		163	- -	23.6	- -	49.4
Urea	120	197	200	29.6	22.8	48.3	51.4
OUN	120	184	195	30.7	23.4	48.3	51.1
ESN	120	197	192	30.0	22.5	48.4	51.6
Urea	160	190	200	29.3	23.9	48.3	50.9
OUN	160	197	202	29.6	23.1	48.0	51.6
ESN	160	198	198	29.4	23.3	48.1	51.1
Urea	200	196	202	31.6	24.0	47.9	51.0
OUN	200	196	200	30.8	21.9	47.8	51.9
ESN	200	186	198	29.3	23.6	49.0	50.7
$Lsd_{.05}$		17.8	15.1	1.8	1.0	1.1	0.8
CV		6.6	5.8	4.2	5.4	1.6	1.9

[1]Yields adjusted to 15.5 % moisture.

Summary

Corn grain yield was affected similarly by urea and two slow release nitrogen materials. In both years the maximum corn grain yield (near 200 bu/A) on an irrigated Spinks loamy sand occurred with 120 lb N/A. Stalk nitrate content better reflected yield response than did V5 whole plant, ear leaf or grain N content. Soil nitrate and ammonium concentrations increased with N rate and indicated that nitrogen was being released a little more slowly with ESN than with urea. A dense soil layer near 30 inches apparently minimized nitrogen loss by leaching. Nitrogen use efficiency, based on yield and diagnostic tissue N, did not differ greatly among the three materials evaluated.

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