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EVALUATION OF SLOW-NITRIFYING SOLID AND LIQUID FERTILIZERS UNDER FIELD CONDITIONS

R. J. Goos and B. E. Johnson
Department of Soil Science
North Dakota State University
Fargo, ND 58105

I. Project orientation

Field studies were performed to determine if inexpensive slow-nitrifying solid and liquid fertilizers could be identified by combining more than one nitrification inhibition technique. For solid fertilizers the two strategies employed were increased fertilizer granule size and addition of the nitrification inhibitor dicyandiamide (DCD). For liquid fertilizers the two strategies were addition of ammonium thiosulfate (ATS, 12-0-0-26S) and DCD. Treatments utilizing nitrapyrin (NP) were also included.

II. Technique

A "bury bag" approach was employed to evaluate large numbers of possible fertilizers. In short, a nylon mesh bag was placed in a piece of 4 inch electrical conduit as a form. Soil and fertilizers, as described below, were added about an inch at a time, followed by gentle packing. The nylon bag and soil was buried in a 4 inch bucket auger hole. Applications were made in the fall, in late September or early October and in the spring, in late April-early May. The first sampling after fall application was made either at fall freeze-up (mid-November) or at spring thaw. The second sampling was made about corn planting time, mid- to late-May. The two samplings after spring application were made 4 and 8 weeks after application. The plots receiving spring application were seeded to wheat or barley.

The soil samples were air dried, sieved (< 2mm) and analyzed for residual ammonium. Recovery of added N as ammonium was calculated knowing the amount of N added and the mass of original soil in the bag. Since plant uptake, mass flow, and diffusion of N was free to occur, these recovery values should be used for a relative comparison between fertilizer sources.

III. Fertilizers evaluated

A. Solid fertilizers

The solid fertilizers tested included a factorial design of three pellet sizes (0.01, 0.1, and 1.0 g/pellet) by 5 levels of DCD in the pellet (0, 1, 2, 5, and 10% of N as DCD-N). The pellets were manufactured by Mr. George Jones of TVA-NFDC. Ten 0.01 g pellets, one 0.1 g pellet or one 1.0 g pellet were used per bag. Small pellets impregnated with NP were also prepared, frozen to prevent NP volatilization, and kept frozen until installation in the field. For the small pellet treatments, an inch of untreated soil was placed in the bottom of the bag, followed by gentle packing. Next the ten pellets were mixed with the remaining soil and the remaining soil packed gently in the bag. For the 0.10 and

1.0 g pellets half of the soil was gently packed in the nylon bag. A single pellet was added to the middle of the soil mass, followed by addition and packing of the rest of the soil. Plant root growth through the bags was vigorous.

B. Liquid fertilizers

Liquid fertilizers were formulated using urea, ATS and DCD. A potassium chloride variable was also included in the fall applications, but since the effect of KCl was insignificant throughout this experiment, the data is shown averaged across KCl rate. Addition of KCl to fertilizer supergranules was tried in 1987 and KCl was added to liquid fertilizers in 1988. No effect of KCl was observed at any of the sites (over 10 field trials total). Thus, it must be concluded that the chloride effect on nitrification is purely an acid soil phenomenon.

The urea content of all solutions was adjusted so that the total N content of 18.7 g/100 mL. The solutions were: 1. urea alone, 2. urea plus 10% (vol/vol) of ATS, 3. urea plus 2% of the total N as DCD-N (0.56 g DCD/100 mL), and 4. urea plus ATS and DCD. The rate of DCD selected is a relatively low rate of DCD, but was selected to see if ATS could strengthen the DCD effect, as claimed by some companies. The liquid fertilizers were applied as a 0.25 mL spot to the center of the soil in the nylon bag. Thus, the application rate and method was similar to the 0.10 g solid urea pellets.

III. Results

A. Solid fertilizers

i. Fall applications

The effect of urea pellet size and DCD on recovery of N as ammonium is found in Tables 1 and 2. Even though the N applications were made late in the fall, there was considerable nitrification at the Fargo and Minot sites at the first sampling (Table 1). The first Fargo sampling was taken in mid November. Most of the N had been nitrified between application in late September and mid-November, as only 23% of the N applied as 0.01 g urea pellets could be recovered as ammonium. Standard NDSU recommendations are that fertilizers applied after 15 September are nitrified very slowly because of low soil temperatures and thus are not susceptible to great overwinter leaching/denitrification losses. Data such as this implies that late fall nitrification can be greater than we currently assume, particularly with non-localized applications.

Adding DCD to the 0.01 g pellets increased the recovery of N as ammonium. There did not seem to be a great advantage of applying greater than 1% of N as DCD. The effect of going to a larger pellet size was dramatic. Using a 0.1 g pellet was about equal, on the average, to using 0.01 g pellets with DCD. Adding even 1% DCD to the 0.1 g pellets increased N recovery as ammonium to greater than 50%. The large 1.0 g pellets gave the highest recovery of all. There was little advantage of adding DCD to the large pellets at this sampling.

This data agrees with the findings of Mahli and Nyborg in Alberta, who found that localization of urea by banding, nesting, or placement as large pellets was quite effective in reducing overwinter N losses from denitrification.

The data from the second sampling is found in Table 2. There was little N remaining as ammonium from the 0.01 g pellets, and little benefit of DCD with this pellet size. The 0.10 g pellets with no DCD were essentially all nitrified by mid- to late- May. Adding DCD did increase the recovery of N to 12-26%.

The results from the large pellets were quite impressive. The 1.0 g pellet without any DCD had 22% of its N as ammonium, greater than observed with 0.01 g pellets with any rate of DCD or NP. Adding even 1% of N as DCD increased this value to 36%. With 2-5% of N as DCD the recovery of N as ammonium was about 40%, which is considerable, considering the sampling was taken over 7 months after application.

The results from the fall application study indicate the value of fall fertilization localization. Also, it seems that DCD has some value, even at very low rates.

ii. Spring applications

Nitrogen recovery as ammonium either 4 or 8 weeks after spring application is shown in Tables 3 and 4. The conventional 0.01 g pellet without nitrapyrin was essentially totally nitrified after 4 weeks (Table 3). The addition of DCD to the small pellets increased this value to 22-23% on the average. There was a considerable site interaction, though. The effect of DCD was non-existent at Fargo, very strong at Carrington, and intermediate at Leonard. It isn't known why there was such a divergent site x DCD interaction. We will check the rainfall records to see if there was dramatic difference in rainfall.

The data shows that increasing pellet size and DCD level in the pellet both increased N recovery as ammonium. Again, some effects of DCD were noticed even at the 1% rate. The large pellets with DCD gave superior recovery of N as ammonium.

The data from the second sampling is given in Table 4. Eight weeks after wheat or barley seeding is well into the growing season, usually correlating to flag leaf emergence or extension, depending on the year. There was essentially no N left as ammonium with the 0.01 g pellets at any rate of DCD. The 0.1 g pellets with any level of DCD gave about 11-13% recovery as ammonium on the average. The large pellets without DCD gave, on the average, 12% recovery as ammonium. This value was increased to 24-30% by the addition of DCD. It is interesting to note that for the 0.10 and 1.0 g pellets that the 1% DCD treatment wasn't a lot different than higher levels of DCD addition. It seems that the level of DCD needed to slow nitrification is quite a bit lower than previously recommended, particularly if there is some attempt to localize the fertilizer application.

B. Liquid fertilizers

i. Fall applications

The effect of ATS and DCD on nitrification of liquid fertilizers is shown in Tables 5 and 6. Recovery of unammended solubilized urea as ammonium averaged 44% (Table 5). The addition of ATS significantly increased this value at all three sites to an average of 61%. The effect of ATS or ATS-DCD was about the same, indicating that ATS can have some value as a nitrification inhibitor under these conditions. The recovery of N from the ATS-DCD treatment was higher than for DCD alone, particularly at the Fargo site, indicating that there might be some benefit of having both in a fertilizer band.

The results from the second sampling show a modest effect of ATS at the Minot site, increasing the N recovery as ammonium from 2 to 10%. The effect of DCD was significant at all sites, and there seemed to be some benefit of having both ATS and DCD in the fertilizer droplet at the Carrington and Minot sites.

ii. Spring applications

The experimental design was changed slightly, with a liquid urea plus NP treatment added. There was a significant effect of ATS at the Carrington site at the first sampling (Table 7), increasing ammonium recovery from 33 to 57%. This effect was not observed in the presence of DCD. ATS addition increased recovery from 18-32% at Leonard, but the effect was not statistically significant. Neither ATS nor DCD had any effect at the Fargo site, which agrees with the pellet data in Table 5.

At the second sampling, 8 weeks after application, there was a trend towards an ATS effect at Carrington and Leonard, but it was not significant. DCD gave a strong effect at Carrington, but not at the other sites. Averaged across all sites, 10-15% of the original N application could be held as ammonium by using ATS and/or DCD. It is not known whether this is a large enough control of nitrification to influence disease resistance.

IV. Discussion

Our goal is to develop inexpensive slow-nitrifying fertilizers in an attempt to improve the nutrition of spring wheat. Our conceptual goal, based on our greenhouse experience and sheer conjecture, is to concoct a fertilization system that will keep at least 20-25% of the N in the ammonium form through heading.

Our reasoning for this goal is based on recent greenhouse and field studies. Wheat was very responsive to "enhanced ammonium supply", as shown in the studies conducted at the TVA by Camberato and Bock. They have shown tillering increases, biomass yield increases, and grain yield increases by keeping part of the N in the ammonium supply. Our greenhouse studies at NDSU have also shown that tan spot can be largely controlled through ammonium nutrition, and one field study in 1988 showed that spring wheat had significantly less leaf rust when fertilized with urea-DCD rather than urea.

The problem with adopting slow-nitrifying technologies to date has been its cost. Adding the common rate of NP costs $5-6/A and adding 5% of N as DCD-N would cost about the same (with a 75 lb/A N rate). These studies have shown that fertilizer localization, which should be achievable through banding, plus rates of DCD as low as 1% of N can perhaps give us 10-40% of the N supply as ammonium as late as 8 weeks into the growing season. Our challenge now is to apply this knowledge in a 2-step way. The first step will be to look at banded UAN-ATS-DCD mixtures as applied by commercial equipment to determine if indeed as low as 1% of N as DCD-N can give us 20-25% of N as ammonium through heading.

Although our primary emphasis is on the providing of ammonium nutrition to wheat, our research has broader applications to the conservation of N. Soil scientists have long searched for new ways to slow nitrogen release so as to reduce denitrification and nitrate leaching, and our research into low cost slow-nitrifying fertilizers certainly aids in this search.

Table 1. Effect of urea pellet size and DCD on the recovery of N as ammonium. First sampling after fall application, 1988-1989.

Pellet size	DCD	Site: Fargo[+]	Site: Carrington	Site: Minot	Average
g	% of N	-------% recovery as (urea + ammonium)-N-----			
0.01	0	23	40	7	23
	1	30	41	42	38
	2	30	53	40	41
	5	35	38	41	38
	10	33	43	44	40
0.10	0	47	65	18	38
	1	55	59	55	56
	2	57	62	56	58
	5	57	57	76	63
	10	48	54	61	54
1.0	0	71	57	39	56
	1	70	56	47	58
	2	71	56	50	59
	5	67	53	50	57
	10	61	55	48	55
Pellets + NP[++]		34	48	46	43
SE[+++]		5	3	5	
Sig of F (Pr>F)					
Size		<0.01	<0.01	<0.01	
DCD		NS[++++]	0.06	<0.01	
Size x DCD		NS	NS	0.02	

[+]Fargo site was sampled in late fall, others in early spring.
[++]0.01 g pellets impregnated with nitrapyrin. This treatment is for qualitative comparsison and is not included in the statistical analysis.
[+++]SE=standard error
[++++]NS=Not significant (Pr>F greater than 0.10)

Table 2. Effect of urea pellet size and DCD on the recovery of N as ammonium. Second sampling after fall application, 1988-1989.

Pellet size	DCD	Site: Fargo+	Carrington	Minot	Average
g	% of N	-------% recovery as (urea + ammonium)-N-----			
0.01	0	0	2	1	1
	1	2	10	1	4
	2	2	7	1	3
	5	5	6	3	5
	10	6	20	4	10
0.10	0	2	2	1	2
	1	9	24	4	12
	2	9	45	15	23
	5	13	52	13	26
	10	12	34	17	21
1.0	0	26	26	15	22
	1	37	49	23	36
	2	38	51	27	39
	5	35	53	31	40
	10	31	47	34	37
Pellets + NP++		9	22	20	17
SE+++		2	4	3	
Sig of F					
Size		<0.01	<0.01	<0.01	
DCD		<0.01	<0.01	<0.01	
Size x DCD		0.03	<0.01	NS	

+Fargo site was sampled in late April, others in late May.
++0.01 g pellets impregnated with nitrapyrin. This treatment is included for qualitative comparison only and is not included in the statistical analysis.
+++SE=standard error
++++NS=Not significant (Pr>F greater than 0.10)

Table 3. Effect of urea pellet size and DCD on the recovery of N as ammonium. First sampling after spring application, 1989.

Pellet size	DCD	Site: Fargo	Carrington	Leonard	Average
g	% of N	-------% recovery as (urea + ammonium)-N-----			
0.01	0	0	1	4	2
	1	0	38	27	22
	2	0	45	23	23
	5	1	39	26	22
	10	1	37	28	22
0.10	0	1	8	4	4
	1	3	54	17	25
	2	4	59	16	26
	5	2	60	35	32
	10	10	57	35	34
1.0	0	21	51	26	33
	1	20	62	33	38
	2	28	66	36	43
	5	27	66	40	44
	10	27	65	31	41
Pellets + NP+					
SE++		4	2	4	
Sig of F (Pr>F)					
Size		<0.01	<0.01	<0.01	
DCD		NS+++	<0.01	<0.01	
Size x DCD		NS	<0.01	0.01	

+0.01 g pellets impregnated with nitrapyrin. This treatment is for qualitative comparsison and is not included in the statistical analysis.
++SE=standard error
+++NS=Not significant (Pr>F greater than 0.10).

Table 4. Effect of urea pellet size and DCD on the recovery of N as ammonium. Second sampling after spring application, 1989.

Pellet size	DCD	Site: Fargo	Carrington	Leonard	Average
g	% of N	-------% recovery as (urea + ammonium)-N-----			
0.01	0	2	0	2	1
	1	1	0	5	2
	2	1	3	6	3
	5	1	0	5	2
	10	1	5	5	4
0.10	0	1	5	4	3
	1	2	13	19	11
	2	1	20	11	11
	5	1	22	16	13
	10	1	23	9	11
1.0	0	2	25	9	12
	1	3	40	28	24
	2	8	43	29	27
	5	14	44	31	30
	10	16	44	26	29
Pellets + NP+					
SE++		2	3	2	
Sig of F (Pr>F)					
Size		<0.01	<0.01	<0.01	
DCD		0.01	<0.01	<0.01	
Size x DCD		<0.01	0.04	<0.01	

+0.01 g pellets impregnated with nitrapyrin. This treatment is for qualitative comparsison and is not included in the statistical analysis.
++SE=standard error

Table 5. Effect of liquid fertilizer composition on recovery of applied N as ammonium, first sampling after fall application, 1988-1989. Data averaged across KCl rate.

ATS	DCD	Site			
		Fargo[+]	Carrington	Minot	Average
--%[++]---		----------% recovery of N as ammonium------			
0	0	46	63	22	44
10	0	53	69	61	61
0	2	54	68	64	62
10	2	62	71	65	66
SE[+++]		4	2	2	
Sig. of F (Pr>F)					
ATS		0.05	0.08	<0.01	
DCD		0.02	0.10	<0.01	
ATS x DCD		NS[++++]	NS	<0.01	

[+]Fargo site was sampled in late fall, others in early spring.

[++]ATS rate expressed as % of liquid fertilizer volume, DCD rate expressed as % of total N applied.

[+++]SE=standard error

[++++]NS=Not significant (Pr>F greater than 0.10)

Table 6. Effect of liquid fertilizer composition on recovery of applied N as ammonium, second sampling after fall application, 1989-1990. Data averaged across KCl rate.

ATS	DCD	Site			
		Fargo[+]	Carrington	Minot	Average
----%[++]--					
0	0	3	3	2	3
10	0	7	12	10	10
0	2	17	34	13	21
10	2	18	41	21	27
SE[+++]		1	7	3	
Sig. of F (Pr>F)					
ATS		NS[++ ++]	NS	0.02	
DCD		<0.01	<0.01	<0.01	
ATS x DCD		NS	NS	NS	

[+]Fargo site was sampled in early May, the others in late May
[++]ATS rate is expressed in % of liquid fertilizer volume, DCD rate is expressed as % of the total N applied
[+++]SE=standard error
[++++]NS=not significant (Pr>F greater than 0.10)

Table 7. Effect of liquid fertilizer composition on recovery of applied N as ammonium, first sampling after spring application, 1989.

ATS	DCD	Site			
		Fargo	Carrington	Leonard	Average
---%[+]-----		----------% recovery of N as ammonium------			
0	0	4	33	18	18
10	0	2	57	32	30
0	2	8	63	47	39
10	2	3	59	53	38
Liquid + NP[++]		19	56	47	41
SE[+++]		2	4	7	
Sig. of F (Pr>F)					
ATS		NS[++++]	0.05	NS	
DCD		NS	<0.01	<0.01	
ATS x DCD		NS	0.02	NS	

[+]ATS rate expressed as % of liquid fertilizer volume, DCD rate expressed as % of total N applied.
[++]Liquid fertilizer with nitrapyrin. This treatment is added for qualitative comparisons with the other treatments and is not included in the statistical analysis
[+++]SE=standard error
[++++]NS=Not significant (Pr>F greater than 0.10)

Table 8. Effect of liquid fertilizer composition on recovery of applied N as ammonium, second sampling after spring application, 1989.

ATS	DCD	Site: Fargo	Carrington	Leonard	Average
---%[+]-----		----------% recovery of N as ammonium------			
0	0	2	12	5	6
10	0	1	19	11	10
0	2	2	28	14	15
10	2	1	21	12	11
Liquid + NP[++]		2	9	13	8
SE[+++]		1	3	5	
Sig. of F (Pr>F)					
ATS		NS[++++]	NS	NS	
DCD		NS	0.02	NS	
ATS x DCD		NS	0.07	NS	

[+]ATS rate expressed as % of liquid fertilizer volume, DCD rate expressed as % of total N applied.
[++]Liquid fertilizer with nitrapyrin. This treatment is added for qualitative comparisons with the other treatments and is not included in the statistical analysis
[+++]SE=standard error
[++++]NS=Not significant (Pr>F greater than 0.10)