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I. Introduction

Research was conducted in two major areas this year. Laboratory research was conducted to ascertain the mechanism by which ammonium thiosulfate inhibits soil urease. This concept is still controversial, as ATS has not inhibited urease in some trials. Also, a knowlege of how ATS inhibits urease would make more evident where ATS may have practical utility as a urease inhibitor.

Field research was conducted in chloride and nitrogen management so as to reduce foliar and root diseases of wheat and barley. Recent research by NDSU, SDSU, and other institutions has established the importance of chloride nutrition in plant health. However, recent research in our laboratory has shown convincing evidence that providing a wheat plant with even 25% of its N supply as ammonium can greatly reduce foliar diseases, especially tan spot. With these two concepts in mind, field research was performed to find inexpensive "slow release" N fertilizers under field conditions.

Growing season conditions were the poorest in 7 years due to record high temperatures and poor rainfall from March through mid-July. The plant analysis data are not reported here, as the chemical analyses are not complete and the overall growth of the crops was well below average at all sites. Reliable soil nitrification data was obtained and it is possible to make conclusions as to possible new slow release fertilizers.

II. Laboratory Studies with ATS.

Ammonium thiosulfate is unique amongst the identified urease inhibitors in that it does not inhibit purified urease. The usual case is that soil urease inhibitors are very potent inhibitors of purified urease. Also, it has been shown that the effect of ATS as a urease inhibitor is strengthened by "dribbling" the fertilizer. ATS has failed to inhibit urease in some laboratory trials where it was mixed throughout the soil mass. ATS has only inhibited urease when used in concentrated liquid fertilizer solutions. The above observations about ATS illustrate two things: 1. ATS must inhibit urease by an indirect mechanism, and 2. relatively high concentrations of ATS must be present (as would exist when a droplet of concentrated fertilizer contacts the soil).

Many experiments were conducted to ascertain the mechanism by which ATS inhibits soil urease, and a theory was tested which would explain the above observations. ATS is a chemically active reducing agent, and the first step of ATS oxidation (thiosulfate to tetrathionate) is abiotic and rapid. This oxidation step readily uses iron and manganese oxides as the electron acceptor, liberating soluble iron and manganese. Iron and manganese ions can inhibit urease by reaction with the sulfhydryl groups at the catalytic center.

Several experiments were conducted to test this theory, and one experiment seems to confirm it. Samples of a Fargo silty clay were reacted with sodium sulfate or sodium thiosulfate (0.2 M) overnight. The next day the original treatment was removed by repeated extraction and centerfugation. The soil was then tested for urease activity or soluble iron or manganese.

The results are shown in Table 1. Urease activity was inhibited 40% by thiosulfate pretreatment even though the original treatment had been removed by extraction and centerfugation. Iron solubility was increased as indicated by the ammonium acetate and HCl extractants. Manganese solubility was greatly increased, and undoubtedly a good deal of soluble manganese was previously removed by the extensive extraction and centerfugation steps.

The experiment confirms our theory that the effect of ATS on soil urease is totally indirect. This would also explain why ATS has no effect on purified urease on the absence of soil. Since no soil is present to release manganese and iron, ATS has no effect on purified urease. This theory would also explain why ATS must by present in a concentrated fertilizer retention zone to inhibit urease.

III. Field experiments with slow release N fertilizers.

A. Fertilizers used.

Fertilizers studied included traditional fertilizers--granular urea and granualar muriate of potash. Also, nitrapyrin-impregnated urea granules were included. The nitrapyrin was added at a rate of 0.56 kg of active ingredient per 150 kg of urea. Specialty products tested were urea supergranules (1.0 g per supergranule) and urea-KCl granules (1.0 g urea and 0.67 g KCl per granule). The reason for testing the supergranules was as follows: large granules or "nests" of conventionally-sized urea granules have been shown to nitrify more slowly than conventional urea in many trials. Perhaps if the nitrification rate of large urea supergranules was slow enough, then the plants could avoid accumulation of very high levels of nitrate in their tissues and perhaps also receive more of their N as ammonium, rather than nitrate. This should increase plant disease resistance. The reason for testing the urea-KCl supergranules was to determine if the high levels of chloride in the fertilizer retention zone could retard nitrification even further. The supergranules were manufactured by Mr. George Jones of TVA by compaction of commercial-grade granular fertilizers.

B. Large-plot experiments

The purpose of these experiments was to compare nitrogen materials and chloride fertilization on nitrification rate, nitrate accumulation, and common root rot severity. The purpose of these experiments had to be modified as the growing season progressed. Rainfall and temperatures were quite unfavorable for small grains (Table 2), and poorer than desired stands were obtained at every site.

Enough stand was available at each site to take soil samples to estimate nitrification, but later rainfalls caused late germination of grain and the plant samples, disease ratings, and yield measurements were all compromised. The best stands were obtained at Garrison and Williston, and disease data from these sites are presented here.

Treatments in the large plot studies were: granular urea, granular urea plus KCl granules, nitrapyrin-impregnated urea, and nitrapyrin-impregnated urea plus KCL. Soil samples were also taken from non-fertilized areas. Fertilizer rates were 150 kg of urea/ha and 100 kg of KCl/ha. The supergranules treatments were applied so that 1/3 of the fertilizer was applied as conventional granules and 2/3 of the fertilizer was applied as supergranules. This was to provide a mixture of fast and slow release fertility for the crop. Description of the sites is shown in Table 3.

Fertilizers were applied by broadcasting followed by incorporation to at least 10 cm with two passes of a tillage implement. Each plot receiving nitrapyrin was incorporated the immediately after fertilizer application, so that the exposure of the urea granules to the air was generally less than 5 minutes. Thus nitrapyrin volatilization was kept to a minimum. Wheat or barley was seeded immediately after fertilizer application.

Soil samples from those plots not receiving supergranule materials were taken 4 and 7 weeks after fertilization. Four cores per plot were taken to 12.5 cm, mixed well, and a subsample was air-dried and analyzed for ammonium and chloride extractable by 0.5 M potassium sulfate. Common root rot was measured by the standard 1-4 rating scale on all plots. A randomized complete block with 5 or 6 replicates was used. The plots were seeded immediately after fertilizer incorporation.

C. Bury bag experiments

The nitrification rate of urea supergranules could not be studied by the same technique used to study the nitrification rate of the granular fertilizers. The spacial distribution of the supergranules (about 1 per square foot) was too great for the sampling procedure used above. Thus, it was decided to study the nitrification rates of individual supergranules buried with soil in open-mesh nylon bags to estimate their nitrification rates in the large plots.

Immediately after seeding the large plot studies, topsoil was taken from an unfertilized area adjacent to the large plot trial, sieved (< 2 mm mesh), mixed, and weighed into 600 g portions (wet weight, dry weight averaged 500 g). A nylon mesh bag was placed into a cylinder about 10 cm diameter by 7.5 cm long. About one half of the soil was added to the cylinder, with gentle packing. Next the supergranule was placed in the center of the cylinder. The remaining soil was placed in the cylinder. The bag was tied shut, and the bag was removed from the cylinder and placed into a 10 cm diameter hole between the rows of grain. The depth of the hole was such that the depth of the supergranule was about 7.5 cm deep. The bag was covered with 2.5 cm of topsoil. The buried bags were installed in a area adjacent to the large plot studies. The treatments were a control treatment, one urea supergranule per bag, and one urea-KCl supergranule per bag. Four replicates were employed and bags were removed for analysis at the same time as soil samples were taken from the large plot experiment.

At sampling time appropriate bags were removed from the ground, and the soil in the bags was air-dried, mixed, ground, and analyzed for extractable ammonium and chloride.

D. Results-nitrification

The nitrification data was calculated in terms of percent recovery of applied urea as soil ammonium and percent recovery of applied chloride. The results after four weeks is shown in Table 4. Nitrification of granular urea was essentially complete after 4 weeks at all sites except Garrison, where nitrification was 88% complete. Nitrification was also essentially complete with the granular urea + KCl treatments. No differences due to chloride addition was noted. Chloride had completely been leached from the topsoil at Carrington during the first four weeks, but substantial chloride remained at the other sites.

Nitrapyrin-impregnation of urea slowed nitrification, but nitrification still averaged 80% complete after four weeks. Considerable differences existed between sites. Considerably more ammonium remained at the Garrison and Williston sites. Presumably this is due to less water movement at these sites during the first four weeks, as these sites also had the highest chloride recoveries. As with unimpregnated urea, KCl fertilization had little effect on nitrification.

Nitrification of urea supergranules was at least comparable to nitrapyrin-impregnated urea after four weeks. Recovery of applied urea as ammonium was greater for supergranules than for nitrapyrin-impregnated urea at Carrington and Garrison, and recoveries were similar at the other two sites. There was no effect of KCl additon to the supergranule on nitrification. This is surprising considering the very high rate of chloride added to the soil in the bag (about 630 ppm) and that a great deal of this chloride (as much as 400 ppm) was still found after 4 weeks. This is pretty convincing evidence that chloride does not inhibit nitrification on the neutral to alkaline soils of North Dakota.

Nitrification of granular urea was complete at all sites after 7 weeks (Table 5). There was no effect of applied granular KCl fertilizer on nitrification. Most of the chloride had been moved below the sampling depth at all sites, with 30% being the highest recovery observed. Nitrapyrin was still influencing nitrification, although nitrification averaged 88% complete. Again, granular KCl had no influence on nitrification.

Nitrification of urea supergranules was completed at Carrington and Minot by 7 weeks. At the other two sites however, the ammonium recovery for the supergranules was superior to nitrapyrin-impregnated urea. Percolation of water was undoubtedly the major factor influencing the nitrification rate of the supergranules. Chloride recovery within the bags was zero at Carrington and Minot while considerable chloride still remained in the urea-KCl bags at the other two sites. Thus, nitrification rate of urea supergranules will be influenced by water infiltration and the potential of urea supergranules as a slow release fertilizer will depend upon the climate.

E. Results-common root rot and grain yield

The effect of N source and chloride on common root rot is presented in Table 6. There was no effect of treatment at Garrison. There was a significant effect of nitrapyrin on common root rot at Williston. Nitrapyrin was more effective in inhibiting nitrification at Williston than Garrison after 7 weeks. The urea supergranule treatments did not lead to reduced common root rot, even though considerable ammonium remained after 7 weeks. We have no ready explanation for this. Perhaps the plant nitrogen uptake data, when completed, will provide an explanation. It is possible that less of the urea supergranule N was available to the plants, due to the dry growing season and limited ability of the plant roots to utilize the highly concentrated zones of N fertility. We have no explanation as to why there was no effect of chloride fertilization on common root rot. There was no effect of treatment on yield (Table 6).

Table 1. Effect of salt pretreatment on urease activity and extractable iron and manganese in a Fargo silty clay.

Salt Pretreatment	Urease Activity‡	DTPA Extractable Fe	DTPA Extractable Mn	NH_4OAc (pH 4.8) Extractable Fe	NH_4OAc (pH 4.8) Extractable Mn	0.1 M HCl Extractable Fe	0.1 M HCl Extractable Mn
	mg NH_4-N $kg^{-1}h^{-1}$	mg kg^{-1}					
Na_2SO_4	121b	62b	18a	6a	37a	4a	104a
$Na_2S_2O_3$	73a(40)	58a	100b	7b	118b	14b	178b
SE†	1	1	1	<1	<1	1	<1

‡ Figure in parenthesis refers to the percent inhibition of urea hydrolysis.
† SE = Standard error.

Data in the same column followed by a different letter are significantly different at the 0.05 level by F test.

Table 2a. Precipitation data

Site	Period			
	April 1 to seeding+	Seeding to first soil sampling†	First to second soil sampling++	Second soil sampling to Aug 10
	inches			
Carrington	0.08	3.42	0.38	10.77
Garrison	0.20	1.47	1.11	10.47
Minot	0.05	1.28	1.51	5.83
Williston	0.11	1.69	0.72	4.22

+ Seeding was 27-30 April.

† First soil sampling was 26-27 May

++Second soil sampling was 15-16 June

Table 2b. Air Temperature data, Minot, North Dakota, 1987.

Measures	April	May	June	July
	°F			
Average Air Temp.	50.0	59.5	68.0	67.7
Departure from normal	+9.8	+6.0	+5.0	-0.9

Table 3. Site characteristics.

Site	Soil Series	0-24 inch NO_3^--N	0-24 inch Cl	Previous Crop	Crop+
		——lb/A——			
Carrington	Heimdahl 1	240	75	Barley	Barley
Garrison	Williams 1	43	<5	Fallow	HRSW
Minot	Hammerly-Gilby 1	38	<5	HRSW	HRSW
Williston	Max 1	25	<5	HRSW	HRSW

Other soil analyses (pH, olsen P, etc.) pending analysis.
+Barley variety was 'Morex', HRSW variety was 'Len'.

Table 4. Recovery of applied ammonium and chloride as influenced by fertilizer material, four weeks after application.

Fertilizer+	Site: Carrington	Garrison	Minot	Williston	Average
	% Ammonium recovery				
Urea	2	18	2	2	6
Urea + KCl	2	11	0	2	4
Urea + NP	9	27	18	31	21
Urea + NP + KCl	13	38	9	44	26
Urea SG	17	54	19	37	32
Urea + KCl SG	15	59	19	38	33
	% Chloride recovery				
Urea + KCl	0	53	23	80	39
Urea + KCl SG	0	64	45	37	37

+ Urea = Urea granules, Urea + KCl = urea granules + KCl granules, urea + NP = nitrapyrin-impregnated urea granules, urea + NP + KCl = nitrapyrin-impregnated urea granules + KCl granules, urea SG = urea supergranules, urea + KCl SG = urea + KCl supergranules.

Table 5. Recovery of applied ammonium and chloride as influenced by fertilizer material, seven weeks after application.

Fertilizer+	Site				
	Carrington	Garrison	Minot	Williston	Average
	% Ammonium recovery				
Urea	0	2	0	2	1
Urea + KCl	0	2	2	4	2
Urea + NP	4	11	18	16	12
Urea + NP + KCl	4	9	11	18	11
Urea SG	2	26	1	16	11
Urea + KCl SG	1	23	0	17	10
	% Chloride recovery				
Urea + KCl	0	23	7	30	15
Urea + KCl SG	0	17	0	29	12

+ Urea = Urea granules, Urea + KCl = urea granules + KCl granules, urea + NP = nitrapyrin-impregnated urea granules, urea + NP + KCl = nitrapyrin-impregnated urea granules + KCl granules, urea SG = urea supergranules, urea + KCl SG = urea + KCl supergranules.

Table 6. Effect of fertilizer materials on common root rot and grain yield.

Site	Fertilizer Materials					
	Urea	Urea + KCl	Urea + NP	Urea + NP + KCl	Urea SG	Urea + KCl SG
	Common Root Rot†					
Garrison	2.9	2.9	2.9	2.9	2.8	2.8
Williston	3.0	3.1	2.8	2.7	3.1	2.7
	Grain Yield, bu/A					
Garrison	32.1	32.8	32.3	34.0	21.4	31.4
Williston	10.2	9.3	11.5	9.1	11.5	10.6

† 1 = none 2 = slight 3 = moderate 4 = severe