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Spring-Applied Nitrogen Fertilizer Influence on Winter Wheat and Residual Soil Nitrate

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Research Question

Injection of anhydrous ammonia (AA) into existing wheat stands in late winter or early spring prior to reproductive growth is performed in some areas. Equipment consisting of a smooth, rolling coulter with a thin (0.5 in.) applicator knife following directly behind has been successfully used to apply AA without significant damage to wheat plants. In combination with spring application of ammoniacal forms of N, cooler soil temperatures would result in reduced nitrification rates allowing the N fertilizer to remain longer as ammonium. Dicyandiamide (DCD) is an N form with nitrification inhibitor properties and can be mixed with common N fertilizers. Use of spring-applied AA or urea-ammonium nitrate (UAN) plus DCD theoretically could enable N to be held on the soil exchange complex, resulting in reduced N mobility. The objectives of this experiment were to determine the effects of spring applications of AA, UAN, and UAN+DCD on grain yield, grain N, subsequent apparent N fertilizer recovery in the grain based on the difference method, and residual nitrate-N distribution in the soil profile in winter wheat.

Literature Summary

Spring N applications have been shown to be effective for increasing grain yields in winter wheat production and can reduce potential for N loss. Dicyandiamide is an N source (65% N) and has been shown to be an effective inhibitor of nitrification in soils. However, experiments conducted with DCD in winter wheat have not shown consistent increases in grain yields. Higher yields and grain N have sometimes been attributed to increased soil ammonium-N availability relative to nitrate-N. Few reports have been published concerning spring-applied AA or UAN+DCD in winter wheat, particularly considering residual soil nitrate-N compared with standard practices using broadcast sprayed UAN.

Study Description

Anhydrous ammonia, UAN, and UAN+DCD (1% w/w N as DCD) were applied for three consecutive years on a sandy loam soil. Applications were made at Feekes growth stage 3 in Years 1 and 2 and at growth stage 5 in Year 3. Nitrogen was applied at 30, 60, and 90 lb N/acre. An unfertilized check and an AA applicator check (0 N applied) were included. Anhydrous ammonia was injected in 18 in. bands perpendicular to wheat drill rows. The UAN and UAN+DCD mixture were broadcast spray-applied. Grain yield and grain N were determined. Soil cores were taken to 4 ft from each plot after harvest, partitioned by depth, and analyzed to determine ammonium-N and nitrate-N.

Applied Questions

Is injection of anhydrous ammonia into established wheat stands prior to reproductive growth a viable N fertilizer management option?

Grain yield responses to applied N were observed. No significant grain yield reduction was attributed to wheat disturbance by the AA applicator. No significant differences in yield responses to fertilization practice were observed, although at the low rate, AA resulted in higher grain yield than UAN (Fig. 1). At the high N rate, grain yield for AA was lower than for UAN. Grain N uptake and apparent fertilizer N recovery

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were higher for injected AA than for broadcast UAN. It is unclear whether this was due to method of placement or enhanced ammonium nutrition. Initial availability may have been improved compared with broadcast N, because AA was injected 6 in. deep and was positionally accessible to rapidly growing roots. Immobilization or volatilization of surface-applied UAN may also have reduced N availability. Postemergence injection of AA was an effective method for applying N compared with broadcast UAN in this experiment. Crop damage as a result of postemergence injection of AA is a concern, and should be carefully assessed before implementing this fertilization technique. Addition of DCD to UAN did not significantly affect plant or soil measurements.

Were any significant differences found for residual soil mineral N?

No significant differences in soil ammonium-N were observed in any year. No large increases in soil residual nitrate-N above the check were generally encountered in the 3 yr of this experiment, but increasing N rates generally resulted in slight increases in residual nitrate-N in Years 1 and 2. Residual soil nitrate-N was small from all treatments (<6 ppm nitrate-N) in all years, but higher for AA than UAN or UAN+DCD in the upper profile in Year 3. Bypassing the surface portion of the organic pool by injection of AA may have had an effect by reducing N immobilization or volatilization.

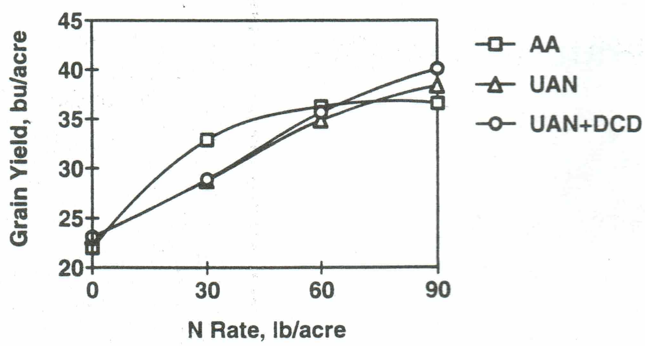

Fig. 1. Three-year means of spring-applied N fertilizer effects on winter wheat grain yield.

Spring-Applied Nitrogen Fertilizer Influence on Winter Wheat and Residual Soil Nitrate

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Spring fertilization may reduce N losses and immobilization compared with fall-applied N in winter wheat (*Triticum aestivum* L.) grain production systems. The objectives of this experiment were to determine the effects of spring applications of varying rates of three N fertilizer sources on grain yield and N concentration, and residual soil profile ammonium-N and nitrate-N distribution. Anhydrous ammonia (AA), urea-ammonium nitrate (UAN), and UAN + dicyandiamide (DCD) (1% w/w N as DCD) were applied for three consecutive years on a sandy loam soil (Udic Argiustoll). Nitrogen was applied prior to reproductive growth at 30, 60, and 90 lb N/acre. An unfertilized check and an AA applicator check (0 N applied) were included. Anhydrous ammonia was injected in 18 in. bands using a rolling coulter applicator. The UAN and UAN + DCD mixture were broadcast sprayed. Soil cores were taken to 4 ft from each plot after harvest. Core samples were partitioned by depth and analyzed to determine ammonium-N and nitrate-N. Grain yield responses to applied N were observed. No significant grain yield reduction was attributed to wheat disturbance by the AA applicator. Grain N uptake and apparent fertilizer N recovery in the grain (based on the difference method) were greater for AA than for UAN. Anhydrous ammonia resulted in significantly greater upper profile soil nitrate-N than either UAN or UAN + DCD in 1 yr. Postemergence injection of AA into established winter wheat was an effective method for applying N when compared with broadcast UAN. Addition of DCD to UAN did not significantly affect measured plant or soil parameters.

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Nitrogen fertilizer management is important in winter wheat production since excess fertilization can cause an accumulation of residual soil nitrate-N and contribute to possible environmental degradation. If N fertilizer is applied preplant, losses or immobilization can occur prior to plant uptake, which greatly affect N use efficiency (Welch et al., 1966; Fredrickson et al., 1982; Olson and Swallow, 1984; Lutcher and Mahler, 1988;

Abbreviations: AA, anhydrous ammonia; DCD, dicyandiamide; UAN, urea-ammonium nitrate.

Table 1. Soil physical and chemical characteristics prior to treatment application, and classification.†

Soil depth	pH‡	Ammonium-N§	Nitrate-N§	Mehlich III P	Mehlich III K	Total N¶	Organic C¶	Sand#	Silt	Clay	Bulk density
in.		ppm				%					g/cu cm
0–6	6.1	8	1	11	148	0.05	0.68	65	18	17	1.79
6–12		7	1			0.05	0.58	71	14	15	1.75
12–18		8	1			0.05	0.65	60	20	20	1.63
18–24		7	1			0.04	0.58	54	20	26	1.77
24–36		7	1			0.03	0.42	62	15	23	1.67
36–48		7	1			0.02	0.23	68	16	16	1.74

Classification: Teller sandy loam (fine-loamy, mixed, thermic Udic Argiustoll)

† Mean check plot values from 4 replications.
‡ 1:1 w/w (soil:H_2O).
§ 2*M* KCl extractable.
¶ Dry combustion method.
# Hydrometer method.

Fowler and Brydon, 1989; Wuest and Cassman, 1992). A management strategy to reduce N loss would be to apply enough fertilizer N in the fall to establish the crop and apply the remaining N requirement in the late winter or early spring before rapid growth occurs. Warm soil temperatures after this time would coincide with rapid wheat growth and thus with increased nutrient demand.

Use of UAN (28-0-0) as a spring topdress material is common. Nitrification inhibitors have been used to enhance yield and prevent N leaching losses. Dicyandiamide is an N source (65% N) with nitrification inhibitor properties and can be mixed with fluid UAN to reduce N mobility. Numerous experiments have been performed concerning the effectiveness of DCD as a nitrification inhibitor (Vilsmeier, 1981; Touchton, 1981; Amberger, 1989; Frye et al., 1989; Malzer et al., 1989; Bronson et al., 1991; Sawyer and Carter, 1993). It is relatively nontoxic to mammals (LD_{50} of 10 000 ppm) and, in contrast to nitrapyrin (also a nitrification inhibitor), is classified as bacteriostatic rather than bacteriocidal. The ultimate products of DCD degradation in soil are CO_2, ammonium, and water (Amberger, 1989). In that incubation trial using ^{15}N labeled ammonium fertilizer at 57°F, DCD inhibited nitrification for 63 d. Vilsmeier (1981) reported that soil temperature, rather than soil moisture, is primarily responsible for DCD degradation; at lower temperatures, the degradation rate of DCD is considerably reduced. In a soft red winter wheat field experiment where DCD-treated urea was used as a broadcast surface topdress on the coastal plains of Alabama, Touchton (1981) found that DCD treatment resulted in significantly higher ammonium-N content in the surface soil 33 and 47 d after treatment. The DCD-treated fertilizers resulted in 39 and 26% more ammonium-N on Days 33 and 47, respectively, compared with normal urea. The DCD treatment did not result in increased grain yield. Touchton (1981) concluded that DCD-treated urea was not likely to be used as an N source in wheat production, although the data were collected in a somewhat dry production year. Bronson et al. (1991) concluded that the use of DCD in a ^{15}N experiment at 90 lb/acre total N applied (with 10% of N rate as DCD) as a fall broadcast and incorporated treatment on winter wheat in Alabama apparently conserved fertilizer N. The addition of DCD to N fertilizer, however, did not result in significant increases in grain yields. Frye et al. (1989) summarized several location-years of experimental data collected on various crops produced in the southeastern USA and concluded that DCD inhibited nitrification, but generally did not increase crop yields. Trends for increased corn (*Zea mays* L.) yields were observed, but were not statistically significant. Malzer et al. (1989) concluded that corn yield response to DCD in the North Central States was best when applied on coarse-textured soils in early spring, prior to rainfall. More recently, Sawyer and Carter (1993) reported winter wheat data from Illinois collected during 2 yr with low leaching potential. Results indicated that UAN broadcast at 90 lb total N/acre in the spring, with DCD added at various rates, decreased grain yields compared with fall-applied treatments. Fall-applied UAN with DCD did not result in large increases in grain yields, but the authors recommended nitrification inhibitor use as a precaution against N loss if all N was fall-applied.

A practice gaining in popularity is injecting AA into wheat stands prior to reproductive growth. This interest is primarily due to the price differential of AA and UAN. Equipment consisting of a smooth, rolling coulter with a thin (0.5 in.) applicator knife following directly behind it has been successfully used to apply AA without significant damage to wheat stands. Application of ammoniacal forms of N in combination with cooler soil temperatures in the spring could result in slower nitrification, allowing the N fertilizer to remain longer as ammonium. This could theoretically enable N to be held on the soil exchange complex, resulting in reduced N mobility. Little information concerning spring-applied AA as an N fertilization practice in winter wheat is available, particularly concerning the environmental aspects of residual soil nitrate-N compared with standard practices.

The objectives of this experiment were to determine the effects of three spring fertilization practices on grain yield, grain N, subsequent apparent N fertilizer recovery in grain based on the difference method, and residual ammonium-N and nitrate-N distribution in the soil profile in winter wheat production systems.

MATERIALS AND METHODS

The experiment was conducted under conventional tillage on a sandy loam soil (Udic Argiustoll) for three consecutive years. The site had been in continuous wheat without fertilization for several years, and soil profile (0–4 ft) nitrate-N was very low (Table 1). No preplant N fertilizer was applied in any year. The experimental area was drilled in 10 in. rows on 13 Oct. 1990, 27 Sept. 1991, and

Table 2. Total and monthly precipitation following fertilizer application at experimental site, 1991–1993.

Month	Year			
	1991	1992	1993	LTA†
	in.			
Feb.	0.0	0.4	--	1.3
Mar.	1.1	1.4	1.7	2.4
Apr.	0.2	5.1	7.1	2.6
May	6.6	5.0	10.7	5.2
June	3.2	3.0	2.7	4.2
Total	11.1	14.9	22.2	15.7

† Long term (60-yr) average for location.

Table 3. Three-year treatment and main effect means for grain yield, grain N uptake, and apparent fertilizer N recovery, 1991–1993.

	Grain			Fertilizer N
	Yield	N	N uptake	recovery
	bu/acre	%	lb/acre	%
Treatments means				
Check	23.1	1.64	23.1	--
AA check	22.0	1.69	22.4	--
AA 30	32.9	1.93	38.6	51.5
AA 60	36.3	2.08	45.9	37.9
AA 90	36.6	2.12	46.9	26.4
UAN 30	28.8	1.66	28.9	19.4
UAN 60	34.9	1.69	35.7	20.9
UAN 90	38.4	1.86	43.0	22.1
UAN+DCD 30	28.9	1.61	28.3	17.2
UAN+DCD 60	35.7	1.77	38.1	25.0
UAN+DCD 90	40.1	1.93	46.0	25.3
SED†	1.6	0.05	2.0	4.6
CV, %‡	6.9	4.0	7.7	23.9
Practice means				
AA	35.3	2.04	43.8	38.6
UAN	34.0	1.73	35.9	20.8
UAN+DCD	34.9	1.77	37.5	22.5
N rate means				
30	30.2	1.73	32.0	29.4
60	35.7	1.84	39.9	27.9
90	38.3	1.97	45.3	24.6
SED	1.5	0.06	1.9	4.6
CV, %	6.0	4.2	6.9	23.9

† SED—standard error of the difference of two treatment means.
‡ CV—coefficient of variation.

9 Oct. 1992. Winter wheat cultivars were seeded at 60 lb/acre and included 'Chisholm' in crop years 1991 and 1992, and 'Karl' in 1993. Diammonium phosphate (18-46-0) was band applied with the seed each year at planting at 13 lb P/acre. Plots were 16 by 40 ft. Three spring fertilization practices were compared. A standard producer practice consisted of UAN topdressed as a broadcast spray. A broadcast spray application of UAN+DCD (1% w/w N as DCD) and injected AA were compared with the standard practice. Nitrogen rates were 30, 60, and 90 lb N/acre. An unfertilized check and an unfertilized AA applicator check (0 N applied) were included to help assess potential stand damage and associated yield reduction due to the AA injection operation. Anhydrous ammonia was applied using a rolling coulter applicator and injected approximately 6 in. deep in 18 in. bands perpendicular to the drill rows. A flow regulator was used to meter the AA. The UAN and UAN+DCD mixture were broadcast-spray applied using a power take-off pump and spray boom calibrated to deliver the prescribed rate. Treatments were applied on 20 Feb. 1991 and 18 Feb. 1992, when wheat was in the Feekes physiological growth stage 3 (Large, 1954). In 1993, N fertilizer application was delayed until 16 Mar. and Feekes growth stage 5. Treatments were replicated four times in a randomized complete block design and applied on the same experimental units each year. A 10 by 40 ft area from each plot was harvested with a small conventional combine on 14 June 1991, 13 June 1992, and 21 June 1993. Grain samples were analyzed for total N using a Carlo Erba CNS NA1500 Series II dry combustion analyzer (Fisons, Milan, Italy). Grain N uptake in the unfertilized check was subtracted from grain N uptake in N treatments to estimate the amount of N fertilizer taken up by the grain. The difference was divided by the N application rate to estimate percentage fertilizer N recovery. Each plot was sampled using a hydraulic soil probe to a depth of 4 ft immediately following grain harvest. Deep soil sampling between AA injection zones was conducted, recognizing that fertilizer N distribution in the soil could be affected by injection location (Jacobson et al., 1986; Bezdicek et al., 1971). Cores were partitioned into six increments representing the 0 to 6, 6 to 12, 12 to 18, 18 to 24, 24 to 36, and 36 to 48 in. depths. Soil samples were air dried at ambient temperature and processed to pass a 0.08-in. (2 mm) sieve. Soil samples were extracted using 2*M* KCl (Bremner, 1965) and analyzed for nitrate-N and ammonium-N using the Lachat-Quikchem automated flow injection analysis system. Nitrate plus nitrate-N was determined using a cadmium reduction procedure. Ammonium-N was determined from the same extract, using the phenolate method.

Analysis of variance using a split-plot in time model was first performed to assess the main effects of year and

Table 4. Analyses of variance on 3-yr means of grain yield, grain N uptake, and apparent fertilizer N recovery, 1991–1993.

		Grain			Fertilizer
				N	N
Source of variation	df	Yield	N	uptake	recovery
All treatments					
Rep	3	**	**	**	**
Trt	10 (8)‡	**	**	**	**
Error	30 (24)				
Contrasts					
Check vs. others	1	**	**	**	--
Check vs. AA check	1	NS	NS	NS	--
AA linear	1	**	**	**	**
AA quadratic	1	**	**	**	NS
UAN linear	1	**	**	**	NS
UAN quadratic	1	NS	*	NS	NS
UAN+DCD linear	1	**	**	**	†
UAN+DCD quadratic	1	NS	*	NS	NS
Practice × N rate					
Rep	3	**	*	**	**
Practice	2	NS	**	**	**
N rate	2	**	**	**	NS
Practice × N rate	4	*	NS	*	**
Error	24				
Contrast					
AA vs. UAN	1	NS	**	**	**
UAN vs. UAN+DCD	1	NS	NS	NS	NS
N rate linear	1	**	**	**	†
N rate quadratic	1	†	NS	NS	NS
AA vs. UAN × N linear	1	**	NS	*	**
AA vs. UAN+DCD × N linear	1	**	NS	**	**
UAN vs. UAN+DCD × N linear	1	NS	NS	NS	NS

*,**,† Significant at the 0.05, 0.01, and 0.10 probability levels, respectively. NS—Not significant.
‡ df in parentheses are for fertilizer N recovery based on deletion of check plots from analysis of variance.

Table 5. Treatment and main effect means for soil nitrate-N, 1993.

	Depth, in.	
	0–6	6–12
	— ppm nitrate-N —	
Treatment means		
Check	3	1
AA check	2	1
AA 30	4	3
AA 60	5	5
AA 90	5	4
UAN 30	3	1
UAN 60	3	1
UAN 90	4	2
UAN+DCD 30	2	1
UAN+DCD 60	3	1
UAN+DCD 90	3	1
SED†	0.8	0.8
CV, %‡	35.3	59.8
Practice means		
AA	5	4
UAN	3	1
UAN+DCD	3	1
N rate means		
30	3	1
60	4	2
90	4	2
SED	0.9	0.9
CV, %	34.9	59.3

† SED—standard error of the difference of two treatment means.
‡ CV—coefficient of variation.

Table 6. Analyses of variance for soil nitrate-N, 1993.

		Depth, in.	
Source of variation	df	0–6	6–12
All treatments			
Rep	3	NS	NS
Trt	10	**	**
Error	30		
Contrast			
Check vs. others	1	NS	NS
Check vs. AA check	1	NS	NS
AA linear	1	**	**
AA quadratic	1	NS	†
UAN linear	1	NS	NS
UAN quadratic	1	NS	NS
UAN+DCD linear	1	NS	NS
UAN+DCD quadratic	1	NS	NS
Practice × N rate			
Rep	3	NS	NS
Practice	2	**	**
N rate	2	NS	NS
Practice × N rate	4	NS	NS
Error	24		
Contrast			
AA vs. UAN	1	**	**
UAN vs. UAN+DCD	1	NS	NS
N rate linear	1	NS	NS
N rate quadratic	1	NS	NS
AA vs. UAN × N linear	1	NS	NS
AA vs. UAN+DCD × N linear	1	NS	NS
UAN vs. UAN+DCD × N linear	1	NS	NS

*,**,† Significant at the 0.05, 0.01, and 0.10 probability levels, respectively. NS—Not significant.

year × treatment interaction. Since interpretation of results did not change, appropriate GLM procedures were used to perform statistical analysis on 3-yr means of plant response variables (SAS, 1988). Statistical differences between treatments were determined using nonorthogonal single degree of freedom contrasts.

RESULTS AND DISCUSSION

Grain Yield

Significant seasonal differences were encountered during the 3 yr experiment, with rainfall amount and distribution varying considerably at this site (Table 2). Analysis of variance on 3-yr means indicated that grain yield responses were quadratic for AA and linear for UAN and UAN+DCD (Tables 3 and 4). Yields were lower for AA at the 90 lb N/acre rate than those observed for UAN or UAN+DCD. This lower yield could have been due to root phytotoxicity from excessive ammonium in the rhizosphere during rapid vegetative and reproductive growth phases. No significant reduction in grain yield was observed as a result of AA injection operations (0 N applied). We expected yield reductions as a result of performing injection operations on established wheat, however, this was not observed. In the first 2 yr, soil moisture conditions were considered ideal for AA application (i.e., moist soil and low compaction, which facilitated applicator shank penetration, allowing for adequate seal). In 1993, soil conditions were wet, but still facilitated good AA application. Immobilization or volatilization of surface spray-applied UAN and UAN+DCD may have contributed to the differential yield response (Fredrickson et al., 1982; Touchton and Hargrove, 1982; Sharpe et al., 1988; Johnston and Fowler, 1991). It is also possible that enhanced ammonium nutrition resulted in significantly higher grain yields at the low AA rate of application. Olsen (1986) discussed the superiority of ammonium nutrition under certain circumstances. Bock (1986) reported that increased ammonium to nitrate ratios can result in enhanced physiological response and sometimes increased yield in wheat.

Grain N Uptake and Fertilizer N Recovery

Apparent N fertilizer recovery in grain has been estimated using the difference method (Jansson and Persson, 1982; Bock, 1984; Olson and Swallow, 1984). When using this technique, overestimation of N fertilizer recovery can occur (Hauck and Bremner, 1976; Westerman and Kurtz, 1974) and errors can be somewhat large. A priming effect of N fertilization application on indigenous soil N has also been observed (Westerman and Kurtz, 1973; Hauck and Bremner, 1976; Riga et al., 1980; Jansson and Persson, 1982). Westerman and Kurtz (1974), however, state that the difference and isotopic methods are more likely to agree when only one crop harvest is obtained and when soil mineralizable N is low. Grain N concentration was increased by N fertilization (Tables 3 and 4). Grain N uptake response to AA rates was quadratic, while a linear response was found for UAN and UAN+DCD. Anhydrous ammonia at the 30 lb N/acre rate resulted in up to twofold increases in fertilizer N recovery when compared with other N fertilization practices, and at the 60 lb N/acre rate, fertilizer N recovery for AA was superior to UAN and UAN+DCD. This effect was diminished at the 90 lb N rate partially due to the quadratic nature of the AA grain yield response. It is unclear whether this difference is attributable to N form or method of fertilizer placement (AA—injected, UAN—broadcast). Because

AA was injected 6 in. deep and was positionally accessible to rapidly growing roots, initial availability may have been improved over broadcast N. Lower availability of surface spray-applied UAN may have been due to volatilization losses (Touchton and Hargrove, 1982; Johnson and Fowler, 1991). Bypassing the surface portion of the microbial and organic pool N sinks by injection of AA may also have had an effect by reducing N immobilization. Sharpe et al. (1988) reported that for wheat produced under conservation tillage, placement of N below the surface layer may improve availability by decreasing immobilization. Varvel et al. (1989) reported that results from ^{15}N labeled fertilizer applied in April to wheat in Nebraska indicated no differences in uptake of labeled fertilizer N for method of placement (broadcast vs. injected). They also stated, however, that cool soil temperatures in that region may not be conducive to N immobilization until late spring.

Soil Analyses

No significant differences in soil ammonium-N were observed in any year (data not shown). No significant differences in soil nitrate-N were observed in any year when comparing the check to the AA applicator check (see Tables 5 and 6 for 1993 data). No large increases in residual soil nitrate-N above the check were generally encountered in the 3 yr of this experiment, but increasing N rates generally resulted in small increases in residual nitrate-N in 1991 and 1992 (data not shown). Residual soil nitrate-N was small from all treatments (<6 ppm nitrate-N) in all years, but higher for AA than UAN or UAN+DCD in the upper profile in 1993 (Tables 5 and 6). It is unclear why AA use would result in higher residual soil nitrate-N in this experiment. It is possible that N volatilization losses from surface applied UAN and UAN+DCD could have been encountered. Microbial immobilization of fertilizer N prior to plant uptake (after incorporation by rainfall into the soil), or loss through surface runoff and leaching may also have occurred to reduce the residual soil nitrate-N levels for broadcast relative to injected N.

SUMMARY

Injection of AA using a rolling coulter applicator with an 18 in. shank spacing was more effective than broadcast UAN for spring applied N at the 30 lb N/acre rate. No significant yield reduction was observed due to wheat disturbance by the AA applicator. Grain N was increased by N fertilization, and grain N uptake and apparent fertilizer N recovery in the grain were greater for injected AA than for broadcast UAN. It is unclear whether this was due to method of placement or enhanced ammonium nutrition. Anhydrous ammonia resulted in higher upper profile soil nitrate-N than either UAN or UAN+DCD in 1 yr. Bypassing the surface portion of the organic pool by injecting AA may have had an effect by reducing N immobilization or volatilization. Addition of DCD (1% w/w N as DCD, as presently marketed) to UAN did not significantly affect soil N or plant responses.

REFERENCES

Amberger, A. 1989. Research on dicyandiamide as a nitrification inhibitor and future outlook. Commun. Soil Sci. Plant Anal. 20:1933–1955.

Bezdicek, D.F., J.M. MacGregor, and W.P. Martin. 1971. The influence of soil-fertilizer geometry on nitrification and nitrite accumulation. Soil Sci. Soc. Am. Proc. 35:997–1002.

Bock, B.R. 1984. Efficient use of nitrogen in cropping systems. p. 273–294. *In* R.D. Hauck (ed.) Nitrogen in crop production. ASA, CSSA, and SSSA, Madison, WI.

Bock, B.R. 1986. Increasing cereal yields with higher ammonium/nitrate ratios: Review of potentials and limitations. p. 1–31. *In* Maximum Wheat Yields Systems Worksh., Denver, CO. 5–7 Mar. Potash and Phosphate Inst., Atlanta, GA.

Bremner, J.M. 1965. Inorganic forms of nitrogen. p. 1179–1237. *In* C.A. Black et al. (ed.) Methods of soil analysis. Part 2. Chemical and microbiological properties. Agron. Monogr. 9. ASA, Madison, WI.

Bronson, K.F., J.T. Touchton, R.D. Hauck, and K.R. Kelley. 1991. Nitrogen-15 recovery in winter wheat as affected by application timing and dicyandiamide. Soil Sci. Soc. Am. J. 55:130–135.

Fowler, D.B., and J. Brydon. 1989. No-till winter wheat production on the Canadian prairies: Timing of nitrogen fertilization. Agron. J. 81:817–825.

Fredrickson, J.K., F.E. Koehler, and H.H. Cheng. 1982. Availability of ^{15}N-labeled nitrogen in fertilizer and in wheat straw to wheat in tilled and no-till soil. Soil Sci. Soc. Am. J. 46:1218–1222.

Frye, W.W., D.A. Graetz, S.J. Locascio, D.W. Reeves, and J.T. Touchton. 1989. Dicyandiamide as a nitrification inhibitor in crop production in the southeastern USA. Commun. Soil Sci. Plant Anal. 20:1969–1999.

Hauck, R.D., and J.M. Bremner. 1976. Use of tracers for soil and fertilizer nitrogen research. Adv. Agron. 28:219–266.

Jacobson, J.S., R.L. Westerman, and P.L. Claypool. 1986. Distribution of applied anhydrous ammonia in soils and germination hazard to winter wheat. Soil Sci. Soc. Am. J. 50:1606–1613.

Jansson, S.L., and J. Persson. 1982. Mineralization and immobilization of soil nitrogen. p. 229–252. *In* F.J. Stevenson (ed.) Nitrogen in agricultural soils. Agron. Monogr. 22. ASA, CSSA, and SSSA, Madison, WI.

Johnston, A.M., and D.B. Fowler. 1991. No-till winter wheat dry matter and tissue nitrogen response to nitrogen fertilizer form and placement. Agron. J. 83:1035–1043.

Large, E.C. 1954. Growth stages in cereals. Plant Pathol. 3:128–129.

Lutcher, L.K., and R.L. Mahler. 1988. Sources and timing of spring topdress nitrogen on winter wheat in Idaho. Agron. J. 80:648–654.

Malzer, G.L., K.A. Kelling, M.A. Schmitt, R.G. Hoeft, and G.W. Randall. 1989. Performance of dicyandiamide in the North Central states. Commun. Soil Sci. Plant Anal. 20:2001–2022.

Olsen, S.R. 1986. The role of ammonium nutrition in higher yields. p. 6–14. *In* J.L. Havlin (ed.) Proc. Great Plains Soil Fertility Worksh., Denver, CO. 4–5 Mar. Kansas State Univ., Manhattan.

Olson, R.V., and C.W. Swallow. 1984. Fate of labeled nitrogen fertilizer applied to winter wheat for five years. Soil Sci. Soc. Am. J. 48:583–586.

Riga, A., V. Fischer, and H.J. van Praag. 1980. Fate of fertilizer nitrogen applied to winter wheat as $Na^{15}NO_3$ and $(^{15}NH_4)_2SO_4$ studied in microplots through a four-course rotation: I. Influence of fertilizer splitting on soil and fertilizer nitrogen. Soil Sci. 130:88–99.

SAS Institute. 1988. The GLM procedure. p. 549–640. *In* SAS/STAT™ user's guide, 6.03 edition. SAS Inst., Cary, NC.

Sawyer, J.E., and J.L. Carter. 1993. Urea-ammonium nitrate management techniques for winter wheat production. J. Prod. Agric. 6:62–67.

Sharpe, R.R., L.A. Harper, J.E. Giddens, and G.W. Langdale. 1988. Nitrogen use efficiency and nitrogen budget for conservation tilled wheat. Soil Sci. Soc. Am. J. 52:1394–1398.

Touchton, J.T. 1981. Effect of didin on nitrification of urea-N, wheat growth and grain yield. p. 53–61. *In* R. Hauck and H. Behnke (ed.) Technical Worksh. in Dicyandiamide, Muscle Shoals, AL. 4–5 Dec. SKW Trostberg Ag., Trostberg, W. Germany.

Touchton, J.T., and W.L. Hargrove. 1982. Nitrogen source and methods of application for no-tillage corn production. Agron. J. 74:823–826.