Immobilization and Uptake of Ammonium and Nitrate Nitrogen in Starter Fertilizer

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Studies using starter fertilizers tagged with $^{15}NH_4NO_3$ or $NH_4{}^{15}NO_3$ indicated that nitrate nitrogen (NO_3-N) in the starter was leached from corn seedling root zone before it could be fully utilized. The presence of dicyandiamide (DCD) in a fluid starter maintained more nitrogen (N) in the NH_4 form, resulting in greater crop N uptake and more microbial immobilization of fertilizer N.

CORN PRODUCERS often supplement their regular fertilizer program by using a starter fertilizer placed near the seed at planting. The intent is to make plants more vigorous during cool spring weather by stimulating early root and shoot growth. Higher N concentration starters are typically produced by adding urea ammonium nitrate (UAN) solution to mixed grade fluid fertilizers. Identifying the fate of ammonium (NH_4) and nitrate (NO_3) in high N starters would aid in determining what formulation is best.

The question of which form of N . . . NH_4 or NO_3 . . . to supply to plants at specific growth stages is an interesting one. Each form has characteristic advantages and disadvantages. A theoretical advantage of NH_4-N is that energy would not have to be expended in reducing NO_3-N to the amide form for assimilation in the developing plant. It has also been determined that NH_4-N is more likely to enhance the uptake of phosphorus (P) in young plants. Disadvantages of NH_4-N in starters include higher susceptibility to immobilization by soil microorganisms, greater potential for soil acidification and the potential for chemical and/or clay fixation in some soils.

In moist, well-drained soils, NH_4 is usually nitrified rapidly to NO_3. Nitrate is carried readily to plant roots by mass flow, but under wet conditions is subject to loss by leaching and denitrification.

Cultural practices affect N availability, crop use and the fate of unabsorbed N. High concentrations of crop residue in surface soil will likely increase the portion of starter N immobilized by soil microorganisms.

Nebraska Research

A study was designed to compare plant uptake and microbial immobilization of NH_4-N and NO_3-N in starter fertilizer for continuous corn. Studies were conducted on a Janude sandy loam and a Hord silt loam. Both are deep, well drained soils with moderately rapid permeability and good water holding capacity.

Single tagged $^{15}NH_4NO_3$ or $NH_4{}^{15}NO_3$ was added to formulated starter fertilizers to trace the N applied in the starter. The starter contained N, P_2O_5, K_2O, sulfur (S) and zinc (Zn) with a composition of 12-12-3-2.5-0.4 the first year and 14-14-3-2-0.6 the second year. The starter supplied 20 lb N/A. Because of leaching losses and low plant ^{15}N recovery the first year, the nitrification inhibitor DCD was included in the starter the second year. In this case, 4 percent of starter-NH_4-N was DCD-N. Tagged starter was diluted with water (2:1) to aid in uniform delivery and was injected with a calibrated hand

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syringe at a depth of 3 inches, at 3-inch intervals, immediately after planting and 2 inches from the row on the center two rows of each plot.

Plant and soil samples were collected at the V3 and V8 growth stages (about 4 and 7 weeks after planting). Soil was sampled at depth increments of 0-2, 2-5 and 5-12 inches to give samples from above, in and below the zone of injection.

Nitrogen Movement

Plant samples collected at the V3 growth stage the first year indicated a much higher apparent plant utilization of starter NH_4 than NO_3 **(Table 1)**. One possible explanation is preferential uptake, but this probably was not the main cause in this case. Spring rainfall had been below normal and, to insure uniform germination and a good stand, the cooperator applied approximately 2 inches of irrigation water through a sprinkler system about five days after planting. Approximately four days later the plots received an additional 1.2 inches of rain. Irrigation and rainfall totaled nearly 5 inches between planting and first sampling.

Soil analysis indicated that this moisture apparently had moved most of the $^{15}NO_3$ out of the top 12 inches of soil by the first sampling date (**Table 2**). Only 1 percent of the starter N applied as NO_3 was found as KCl-extractable inorganic N above the 5-inch depth the first year, compared to approximately 20 percent for $^{15}NH_4$ at the V3 growth stage. The plots were located on a well drained sandy loam soil, which would suggest a low potential for denitrification. In addition, isotope enrichment at the 5- to 12-inch depth showed that $^{15}NH_4$ had also moved downward. Isotope analysis indicated that practically all of the fertilizer $^{15}NH_4$ had either been nitrified or immobilized by the first sampling date, and most likely moved downward as $^{15}NO_3$.

Increased plant utilization of ^{15}N by the V8 growth stage the first year suggested that the roots were beginning to intercept the leached ^{15}N (**Table 1**). Similar utilization of ^{15}N, whether applied as NO_3 or NH_4, between the V3 and V8 growth stages would be expected if both sources were mainly in the same form (NO_3) with similar positional availability in the expanding root zone. This indicated that N applied as NO_3 did not leach much further than that originally applied as NH_4.

Nitrogen Immobilization

The maximum amount of fertilizer ^{15}N in the microbial biomass can be estimated by subtracting the fertilizer-derived ^{15}N in the soil inorganic N pool from the total fertilizer-derived ^{15}N in the soil. Biomass ^{15}N would not exceed this difference value because any ^{15}N fixed by soil clays also would be included in the difference between total soil ^{15}N and inorganic ^{15}N. First year data indicated greater microbial immobilization of NH_4-N despite rapid nitrification (**Table 3**).

Nitrification Inhibitor Effects

Because much of the ^{15}N was leached below the root zone of the V3 plants the first year, the second year of the study

Table 1. Percent utilization (standard deviation in parenthesis) by corn of ^{15}N applied in a starter fertilizer.

Growth stage	Year 1		Year 2			
	$^{15}NO_3$	$^{15}NH_4$	$^{15}NO_3$	$^{15}NO_3$ (+ DCD)[1]	$^{15}NH_4$	$^{15}NH_4$ (+ DCD)
	% Utilization of ^{15}N[2]					
V3	1.0 (0.7)	11.1 (2.4)	2.9 (1.9)	4.4 (2.0)	8.4 (2.2)	16.3 (1.8)
V8	10.1 (4.7)	20.6 (7.2)	51.5 (6.9)	49.7 (8.6)	61.2 (5.2)	62.6 (1.8)

[1]DCD = Dicyandiamide
[2]Percent utilization of ^{15}N = percent of fertilizer ^{15}N recovered in entire above-ground material.

included the nitrification inhibitor, DCD, with both $^{15}NH_4$ and $^{15}NO_3$ treatments. DCD is an effective nitrification inhibitor for approximately 6 to 10 weeks. It is thought to interfere with the respiration of *Nitrosomonas* genus of bacteria, which are primarily responsible for the first step in nitrification.

At the V3 growth stage in the second year, utilization of fertilizer $^{15}NH_4$ by corn was more than twice that of $^{15}NO_3$ (**Table 1**). The addition of DCD approximately doubled the utilization of fertilizer $^{15}NH_4$ at this growth stage. Without considering other information, plant N uptake data would suggest preferential uptake. However, excess moisture (4 inches of rainfall before emergence and over 7 inches before sampling) removed over 95 percent of the $^{15}NO_3$ out of the top 5 inches of soil by the V3 growth stage (**Table 2**). Although more than half of the $^{15}NH_4$ without DCD could not be accounted for in the above-ground corn tissue or in soil to 12 inches by this date, nearly 15 percent was still available in the $^{15}NO_3$ form in the top 5 inches. With $^{15}NH_4$+DCD, the highest proportion of ^{15}N was still available to the plants, with nearly one-half the applied amount in inorganic forms in the top 12 inches of soil four weeks after planting.

Table 2. Percent of starter fertilizer ^{15}N (standard deviation in parenthesis) recovered in the top 12 inches of soil at the V3 sampling date.

			Soil N fraction		
		Soil depth increment,	Total	KCl extractable ^{15}N	
Year	Treatment	inches	^{15}N	NO_3-N	NH_4-N
			%		
Year 1	$^{15}NO_3$	0-2	1.0 (0.1)	0.3 (0.3)	0.0 (0.0)
		2-5	1.6 (1.1)	0.8 (0.7)	0.0 (0.0)
		5-12	12.8 (1.4)	11.4 (1.4)	0.0 (0.0)
	$^{15}NH_4$	0-2	8.0 (3.5)	3.0 (2.0)	0.0 (0.0)
		2-5	26.6 (9.9)	16.6 (10.5)	0.4 (0.4)
		5-12	27.7 (6.0)	24.9 (4.8)	0.1 (0.1)
Year 2	$^{15}NO_3$	0-2	1.2 (0.4)	0.4 (0.3)	0.0 (0.0)
		2-5	2.6 (2.4)	1.9 (1.6)	0.0 (0.0)
		5-12	9.2 (4.9)	7.7 (4.5)	0.0 (0.0)
	$^{15}NH_4$	0-2	6.5 (3.3)	3.7 (2.6)	0.0 (0.0)
		2-5	12.4 (4.5)	10.3 (5.7)	0.1 (0.1)
		5-12	17.3 (2.9)	15.7 (3.3)	0.0 (0.0)
	$^{15}NO_3$ + DCD	0-2	1.8 (0.5)	0.5 (0.3)	0.0 (0.0)
		2-5	2.7 (1.1)	1.6 (1.0)	0.2 (0.1)
		5-12	11.4 (2.8)	9.9 (2.8)	0.1 (0.1)
	$^{15}NH_4$ + DCD	0-2	23.2 (9.9)	9.8 (2.0)	2.8 (2.0)
		2-5	32.3 (8.3)	13.4 (2.1)	8.4 (2.2)
		5-12	13.7 (4.1)	12.8 (3.7)	0.1 (0.1)

Large increases in crop utilization of ^{15}N at the V8 growth stage for all treatments in year 2 indicate (again) that much of the starter N that had leached out of the upper 12 inches of soil was within the crop root zone by the V8 stage. Although crop utilization of ^{15}N at V8 was much higher in year 2 than year 1, similar increases occurred both years between the V3 and V8 growth stages, whether the ^{15}N was

Table 3. Estimated fertilizer ^{15}N (standard deviation in parenthesis) recovered in soil biomass at the V3 sampling date.

			Method of estimation	
Year	Treatment	Soil depth increment, in.	Difference[1]	Incubation[2]
			%	
Year 1	$^{15}NO_3$	0-2	0.7 (0.3)	0.3 (0.1)
		2-5	0.8 (0.5)	0.7 (0.5)
	$^{15}NH_4$	0-2	5.0 (1.5)	3.3 (2.3)
		2-5	9.6 (3.0)	7.7 (4.0)
Year 2	$^{15}NO_3$	0-2	0.8 (0.2)	0.5 (0.2)
		2-5	0.9 (0.6)	0.6 (0.3)
	$^{15}NH_4$	0-2	2.7 (0.8)	3.0 (1.4)
		2-5	2.0 (1.5)	1.8 (0.6)
	$^{15}NO_3$ + DCD	0-2	1.2 (0.3)	1.1 (0.2)
		2-5	1.1 (0.4)	1.4 (0.6)
	$^{15}NH_4$ + DCD	0-2	10.6 (6.0)	9.3 (4.3)
		2-5	13.3 (3.6)	14.8 (6.2)

[1]Difference + Total percent fertilizer ^{15}N found in soil less percent fertilizer ^{15}N found in KCl extractable inorganic pool.
[2]Derived using the Shen et al. method for determining biomass N.

applied as NO_3 or NH_4. This would be expected if the ^{15}N was mainly in the same form (NO_3) with similar positional availability between V3 and V8.

In addition to increasing plant uptake, DCD also enabled more fertilizer ^{15}N to be taken up by the microbial biomass (**Table 3**), probably by maintaining fertilizer N in the NH_4 form.

Conclusions

Efficient use of starter fertilizer N by young plants is dependent upon keeping the N positionally available. Nitrate-N in starter fertilizer can be readily leached out of the rooting zone of permeable soils before it can be utilized by young plants, although it may be recovered later by older plants. Application of starter N as NH_4 without a nitrification inhibitor only slightly improved plant N uptake. For the soils used in this study, nitrification of NH_4 followed by leaching was a greater barrier than microbial immobilization to the efficient use of starter NH_4.

DCD significantly increased crop utilization and microbial immobilization of starter NH_4. This is probably related to DCD maintaining more starter fertilizer N in the NH_4 form and maintaining positional availability. Under moderate leaching conditions, it may be advantageous to add a nitrification inhibitor to starters to ensure that fertilizer N remains positionally available to young corn plants. ■

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