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Effect of Nitrification Inhibitors on Yield of Planted and Ratooned Grain Sorghum Grown with Conservation Tillage[1]

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ABSTRACT

The use of nitrification inhibitors with ammonium forms of N fertilizer during periods of excessive rain may improve N efficiency and crop yields. In the Southern Coastal Plains (soils are predominately sands, loams and loamy sands with low water holding capacities), grain sorghum (*Sorghum bicolor* L., Moench.) grown in ratoon cropping systems generally has to be fertilized with N during periods of excessive rain. In addition, the sorghum is frequently grown in conservation tillage systems which often increases the probability of losing N via leaching and/or denitrification. The primary purpose of this study was to evaluate the effects of nitrification inhibitors on yield of grain sorghum grown in conservation tillage systems. Treatments included a no N check and 80 and 120 lb N/ac (32% urea-ammonium nitrate solution) applied with and without inhibitors [dicyandiamide (DCD), nitrapyrin (N-Serve®) and etridiazole (Dwell®)]. Treatments were applied to the planted crop three to four weeks after planting, but a uniform N application without inhibitors was used for the ratooned crop. Climatic conditions during the first few weeks after treatment application were favorable for N losses through leaching and denitrification each year. Inorganic N concentrations in the surface soil were higher with than without the inhibitors three weeks after application, but not after six weeks. Each inhibitor, when applied with 80 lb N/ac improved the yield of the planted crop the first year, but only DCD improved yields the second year. No inhibitor increased yields when applied with 120 lb/ac N. In one year, inhibitors applied to the planted crop improved yields of the ratooned crop. The results of this study support the theory that nitrification inhibitors can improve yields when applied with ammonium N if climatic conditions are favorable for N losses during the first few weeks after application.

Additional index words: ***Sorghum bicolor*** **L., Moench, In-row subsoiling, N solution, Urea-ammonium nitrate, Dicyandiamide, Didin® , DCD, Nitrapyrin, N-Serve® , Etridiazole, Dwell® .**

THE application of N fertilizer is a necessary but costly practice that is essential for profitable yields of non-leguminous crops. Utilization of fertilizer N by crops is generally poor and ranges from 25 to 50% (1, 11, 12). Two primary mechanisms, leaching of NO_3^--N and gaseous losses via denitrification, account for major losses of fertilizer N, which reduce N efficiency. Ammonium-N is not subject to these losses, and delaying the conversion of NH_4^+-N to NO_3^--N through the use of nitrification inhibitors offers one means of improving N efficiency.

Soils data from research conducted over the past two decades have shown that a number of chemicals can effectively retard nitrification (8, 16). However, the effects of nitrification inhibitors on crop yields and N uptake have been inconsistent. The use of nitrification inhibitors increased yields (4, 7, 9, 19) and N uptake in some instances (4, 9, 19), while in others their use had little or no effect on yield or N uptake by crops (3, 19, 21).

Yield responses to nitrification inhibitors depend on a number of factors and their interactions. These include N rate applied, soil temperature, pH, texture, organic matter and biological activity. A primary factor, however, is climatic conditions, especially the frequency and intensity of rainfall following N fertilizer application. If climatic conditions, *i.e.*, excess rainfall and temperatures favorable for biological activity, are suitable for N losses via leaching and denitrification, yield responses to nitrification inhibitors can be expected.

In the Southern Coastal Plains, excess rainfall occurs from December through April (17, 20). This period coincides with the planting date necessary for a successful ratoon cropping system for grain sorghum (*Sorghum bicolor* L., Moench) (6).

In recent years, interest in no-till ratoon cropping of grain sorghum has developed. Nitrogen availability to crops in soils managed with conservation tillage systems may be reduced as compared to tilled systems due to: 1) reduced or slowed N mobilization caused by cooler temperatures, higher soil moisture and higher C/N ratios (2, 15); 2) increased leaching of NO_3^--N (18); and 3) increased denitrification (5, 14) caused by increased soil moisture and organic carbon sources.

Early planting necessary for a successful ratooned grain sorghum crop occur during the peak rainy season. This, along with possible reduced N availability under no-till, may create conditions in which plant

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growth and yield can benefit from the use of nitrification inhibitors.

The purpose of this study was to determine the effects of three nitrification inhibitors, nitrapyrin (N-Serve®), etridiazole (Dwell®), and dicyandiamide (DCD, Didin®), on soil mineral N, grain yield and N uptake of planted and ratooned grain sorghum grown in a no-till management system.

MATERIALS AND METHODS

This study was conducted for two years (1982 and 1983) on a Dothan fine sandy loam (Plinthic Paleudults, fine-loamy, siliceous, thermic) in the Southern Coastal Plains of Alabama. The Dothan soils are deep, well drained and have a low water holding capacity (1 inch/ft). The organic matter content was 1% and the cation exchange capacity was 4 meq/100g. The initial soil pH was 6.0 and soil test rating for P, K, Ca and Mg was high.

Peanuts (*Arachis hypogaea* L.) were grown on the experimental area in 1981. During the winter of 1981/82 and 1982/83, rye (*Secale cereale* L.) was grown as a winter cover crop. The sorghum (NK Savanna 5) was no-till planted into the rye with an in-row subsoil planting unit. These implements subsoil under the row and plant in a single operation. Depth of subsoiling was 12 inches. Planting dates were March 11, 1982, and April 24, 1983. Row width was 24 inches and seeding rates were 6 seeds/ft (130,000 seed/ac). Weeds and rye were effectively controlled with a preemergence application of paraquat (½ lb/ac ai) + milogard (3 lb/ac ai) and post direct applications of Lasso (1 lb/ac ai) plus paraquat (0.5 lb/ac ai). Starter fertilizer, 100 lb/ac of 23-20-0 (N-P_2O_5-K_2O), was applied to all treatments at planting. The fertilizers were dropped in the subsoil track and mixed with the surface six to eight inches of soil directly under the seed.

Nitrogen and N plus inhibitor treatments were applied one month after planting in 1982 and three weeks after planting in 1983. Nitrogen rates were 0, 80 and 120 lb N/ac (32% urea-ammonium nitrate solution). Nitrification inhibitors consisted of nitrapyrin (0.5 lb/ac), etridiazole (1 lb/ac) and DCD (2.5 and 5% of the N rate as DCD-N). The inhibitors were applied with the 80 and 120 lb/ac N rates. Although the sorghum was no-till planted, the N and N plus inhibitors were applied in a two to four-inch deep opened furrow approximately four inches from the row. The furrow was covered immediately after application in 1982, but a two-inch rain (during application) prevented the furrow from being covered in 1983. The experimental design was a randomized complete block replicated four times.

The planted crop was harvested on July 19, 1982, and August 9, 1983. After harvesting, the stalks were mowed to a three-inch stubble height and allowed to ratoon. Prior to tillering, the test area was sprayed with paraquat (0.5 lb ai/ac) to kill late emerging crabgrass L (*Digitaria sanguinalis* L.). Within one week after tillering, 80 lb N/ac was applied across the entire experimental area. No other N rate or inhibitor treatments were applied to the ratooned crop. The ratooned crops were harvested on October 26, 1982 and 1983.

Soil samples (0 to 6 and 6 to 12-inch depths) were collected three and six weeks after treatment application in 1982 for inorganic N (ammonium and nitrate plus nitrite) determinations (Kjeldahl procedure). Soil samples were taken only from plots receiving 0 and 80 lb N/ac. Flag-leaf samples were taken from the planted and ratooned crop during the early bloom stage for N determinations. Mature grain from the planted and ratooned crops was analyzed for N concentration. Grain moisture was adjusted to 13% for yield calculations.

Statistical analyses included analysis of variance, paired comparisons and Fisher's Least Significant Differences. The 10% level of probability was used for separating treatment means. Differences between the two rates of DCD were not found, and data from these treatments were averaged.

Rainfall Distribution: Total rain received and distribution (weekly) during the growing seasons are presented in Table 1. Soil moisture at planting was near field capacity in both years; in 1983, planting had to be delayed until late April because of exceptionally wet soils. Because of wet soils at the time of treat-

Table 1. Rainfall distribution in 1982 and 1983 sorghum growing season.

Year	Month	Week 1	Week 2	Week 3	Week 4	Total
		inches				
1982	March	—	—	1.0	1.2	2.2
	April	1.0	0.4	2.7	0.9	5.0
	May	0.0	0.5	0.9	1.5	2.9
	June	1.1	0.4	1.8	3.3	6.6
	July	4.8	2.4	2.8	2.7	12.7
	August	1.7	2.4	0.1	0.5	4.7
	September	2.9	1.9	0.1	0.0	4.9
	October	0.2	1.2	0.0	0.0	1.4
1983	April	0.4	3.0	1.4	2.1	6.9
	May	0.3	0.1	2.4	0.5	3.3
	June	1.7	0.4	1.9	4.0	8.0
	July	2.1	0.0	0.2	1.4	3.7
	August	1.6	0.7	0.1	0.8	4.8
	September	2.8	1.0	0.7	0.0	4.5
	October	0.0	3.2	0.2	0.0	3.4

ment application and rain received within a few weeks after application, climatic conditions should have been favorable for N losses through leaching and denitrification. Rain received during the first, second, third and fourth week after application was 0.5, 0.9, 1.5 and 1.1 inches, respectively, in 1982, and 2.4, 0.5, 1.7 and 0.4 inches, respectively, in 1983. A one-inch infiltration rain will wet an air dry Dothan soil approximately 12 inches deep. The sorghum was not irrigated.

RESULTS AND DISCUSSION

Inorganic Soil N: Based on the ammonium and nitrate concentrations in the soil three weeks after treatment application, it appears that nitrification was reduced by each of the inhibitors (Table 2). The low rate of DCD (2.5% of N rate as DCD-N) was as effective as the high rate (5% of N rate as DCD-N) and both resulted in higher NH_4^+-N levels than N-Serve® and Dwell®. Eight weeks after application, however, differences in NH_4^+-N or NO_3^--N among inhibitors were not found (data not shown), and inorganic N levels in top 12 inches of soil were as high (10 lb/ac) with the O-N treatment as they were with 80 lb N/ac with or without inhibitors. The effectiveness of inhibitors in delaying nitrification is highly dependent on temperatures (10). At temperatures commonly experienced in south Alabama in the spring, inhibitors are not expected to be effective for more than four to six weeks.

Table 2. Soil inorganic N (ammonium and nitrate + nitrite) concentrations in the 0 to 6-inch depth three weeks after application as affected by 80 lb N/ac in 1982 applied with and without nitrification inhibitors.

N Form †	Inhibitor: None	N-Serve®	Dwell®	DCD	FLSD 0.10
	ppm				
NH_4	24	34	42	59	8
NO_3+NO_2	10	15	12	7	NS

† When N was not applied, NH_4^+-N and NO_3^--N concentrations were 13 and 5 ppm, respectively.

Grain yields: Yields of the planted crop, in 1982, ranged from 21 bu/ac without N up to 68 bu/ac with N (Table 3). With the low N rate (80 lb N/ac), the inhibitors improved yields (47 and 58 bu/ac without and with inhibitors, respectively), but there were no differences (P = 0.10) among inhibitors. With the high N rate (120 lb N/ac), inhibitors did not improve yields. N-Serve® and DCD applied with 80 lb N/ac resulted in yields comparable to 120 lb N/ac with or without inhibitors, with the exception that the 120 lb N/ac with DCD increased yields over the 80 lb N/ac with DCD treatment.

Yield of the ratooned crop in 1982 was almost as high as yield with the planted crop (Table 3). Generally, ratooned crop yields will average between 60 and 70% as high as the planted crop. Nitrogen rate and inhibitor variables were not used on the ratooned crop, but there was a residual effect on yield from treatments applied to the planted crop. Inhibitors applied with 80 lb N/ac improved yield of the ratooned crop 17 bu/ac, but there were no differences among inhibitors. When inhibitors were applied with 120 lb N/ac only DCD improved ratooned yields, but yields with 120 lb N/ac, plus DCD were no higher than 80 lb N/ac plus DCD.

Although ratooned crop yields in 1982 were dependent on treatments applied to the planted crop, questionable data points were obtained. There is no logical explanation as to why N-Serve® and Dwell® applied with 120 lb N/ac would result in lower yields (P = 0.15) than when applied with 80 lb N/ac. The yield response to inhibitors, especially with 80 lb N/ac, indicates that the effect of inhibitors on nitrification in warm Coastal Plain soils may last much longer than normally expected, or predicted, through the use of soil N data.

Although the sorghum was planted relatively late in 1983 (April 24), the growing season was much more favorable than the 1982 season, and yields in 1983 were higher than in 1982 (Table 3). When applied with 80 lb N/ac, DCD improved yields 10 bu/ac, but neither N-Serve® nor Dwell® affected yield. With 120 lb N/ac, none of the inhibitors improved yields. Lack of mechanical incorporation because of the two-inch rain immediately after treatment application would probably favor DCD over the other inhibitors, especially N-Serve®. The DCD is highly soluble in water (13) and will most likely move through the soil with the wetting front with the urea. N-Serve® is not water soluble, and N-Serve® and Dwell® will volatilize if not incorporated (16).

Unlike 1982, yield of the ratooned crop in 1983 (Table 3) was not dependent on treatment applied to the planted crop. The ratooned crop yield averaged 69 bu/ac, which was 59% as high as the planted crop.

Flag leaf N: In 1982, N concentration in flag leaf during the bloom stage varied among treatments (Table 4), and the leaf N responses to N rates and inhibitors were similar to grain yield responses. Leaf-N concentrations increased with N rates (1.53 to 2.86% N). Increases in leaf N due to the inhibitors were found with both N rates, and at the low N rate DCD resulted in higher leaf-N concentrations than N-Serve® or Dwell® (3.44 vs 2.94% N).

Although grain yield of the ratooned crop in 1982 was affected by N and inhibitors applied to the planted crop, N concentrations in the flag leaf did not give any indications of a varying N status among the original treatments. When averaged across treatments applied to the planted crop, leaf N level of the ratooned crop was 2.52%.

In 1983, differences in grain yield among N and inhibitor treatments for the planted crop were not reflected in leaf-N concentrations. Leaf-N data were, however, highly variable, and the only difference detected (P = 0.10) was between the O-N check (1.92% leaf N) and all other treatments (2.72% N). The concentration of N in the leaves of the ratooned crop averaged 2.43%, and did not vary among treatments applied to the planted crop.

Grain N: Grain N was determined only in 1983. With the planted crop, there was a grain N response to N and inhibitors (Table 5), and the response was similar to the grain yield response. At the low N rate, DCD resulted in higher N concentrations in the grain than N-Serve® or Dwell®, but neither N-Serve® nor Dwell® resulted in higher N concentrations than the no inhibitor check. With 120 lb N/ac, only N-Serve® resulted in higher grain-N concentrations than the no inhibitor check, but yields were not improved by the inhibitor. Nitrogen concentration in the grain of the ratooned crop was not affected by treatments applied to the planted crop, and this generally agrees with N concentrations in the flag leaves.

Table 3. Grain sorghum yields as affected by applied N and nitrification inhibitors.

Year	Crop	N applied at planting	Inhibitor: None	N-Serve®	Dwell®	DCD	FLSD (0.10)
		(lb/ac)	yield, bu/ac				
1982	Planted	0	21	—	—	—	
		80	47	60	55	60	
		120	64	62	60	68	8
	Ratooned	0	43	—	—	—	
		80	43	60	62	59	
		120	52	51	53	63	10
1983	Planted	0	55	—	—	—	
		80	111	112	112	121	
		120	124	129	116	118	8
	Ratooned	0	69	—	—	—	
		80	69	67	74	70	
		120	69	66	68	65	NS

Table 4. Nitrogen in the sorghum flag leaf during bloom stage as affected by applied N and nitrification inhibitors.

Year	Crop	N applied at planting	Inhibitor: None	N-Serve®	Dwell®	DCD	FLSD (0.10)
		(lb/ac)	leaf N, %				
1982	Planted	0	1.53	—	—	—	
		80	2.66	2.94	2.93	3.44	
		120	2.86	3.34	3.30	3.30	0.26
	Ratooned	0	2.56	—	—	—	
		80	2.62	2.51	2.58	2.40	
		120	2.58	2.49	2.54	2.55	NS
1983	Planted	0	1.92	—	—	—	
		80	2.56	2.71	2.66	2.81	
		120	2.87	2.93	2.66	2.60	0.42
	Ratooned	0	2.45	—	—	—	
		80	2.64	2.34	2.65	2.43	
		120	2.30	2.31	2.30	2.59	NS

Table 5. Nitrogen concentrations in oven-dry sorghum grain in 1983 as affected by applied N and nitrification inhibitors.

Crop	N applied at planting	None	Inhibitor N-Serve®	Dwell®	DCD	FLSD (0.10)
	(lb/ac)	grain N, %				
Planted	0	1.05	—	—	—	
	80	1.34	1.36	1.31	1.56	
	120	1.61	1.84	1.64	1.70	0.19
Ratooned	0	1.35	—	—	—	
	80	1.36	1.26	1.42	1.38	
	120	1.43	1.54	1.41	1.33	NS

CONCLUSIONS

The inhibitors were effective in delaying nitrification of ammonium to nitrate for a few weeks after application; however, all of the ammonium N had nitrified within eight weeks after application. Each of the inhibitors improved yields when applied with 80 lb N/ac in the first year, but only DCD improved yields the second year. Yield improvements with DCD, but not with N-Serve® and Dwell®, in the second year may have been related to application method. When applied with 120 lb N/ac, none of the inhibitors improved yields. Generally, 80 lb N/ac with inhibitors resulted in yields as high as 120 lb N/ac without inhibitors. The residual effect of N and N plus inhibitor applied to the planted crop influenced yields of the ratooned crop in one of the two years. This residual effect of inhibitors suggests that their indirect effect on crop growth and yield can last much longer than normally expected. Leaf-N concentrations during the bloom stage did not necessarily provide a strong indication of the effect of inhibitors on yields. The response of grain N to the inhibitors (1-year data only) followed almost identical trends as grain yields. As with other studies, the results of this study indicate that in situations when climatic conditions favor N losses through either leaching or denitrification, the use of nitrification inhibitors can increase yields.

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