NITROGEN SOURCES, RATES, AND NITRIFICATION INHIBITOR EFFECTS ON BERMUDAGRASS PRODUCTION

By

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CHAPTER I

INTRODUCTION

Bermudagrass (*Cynodon dactylon* L.) production in Oklahoma requires high rates of nitrogen (N) to produce high yields of quality forage. Under the current economic conditions that producers are operating and with increasing costs of N fertilizers as well as application costs, there are three criterion which become critical in evaluating efficient N use. First is increasing dry matter production, secondly, increasing N content of the forage (and hence protein content), and finally doing both of these as economically as possible.

Urea contains the highest percentage of N (46%) of any solid fertilizer currently available, but producers have been hesitant to use urea because of the potential for volatilization losses of the applied N. When urea is applied to the soil it hydrolyzes to produce either ammonia (NH_3), which can volatilize, or ammonium (NH_4^+). Subsequently, the NH_3 or NH_4^+ can undergo microbial oxidation, or nitrification, to produce nitrate (NO_3^-) which can be lost from the soil due to leaching, or, if anaerobic conditions such as waterlogged soils prevail, denitrification occurs. This results in pollution of the ground- and surface water via leaching of NO_3^-, or a gaseous release of molecular N and volatile oxides if denitrification occurs, both of which result in an undesirable loss of N from the root zone.

Since NH_4^+ is not subject to either of these losses it seems desirable to inhibit nitrification. Many chemicals have been shown to effectively inhibit nitrification in the laboratory and greenhouse and have the potential to improve N use efficiency by limiting losses of applied N. The two nitrification inhibitors (NIs) used in this study are nitrapyrin (2-chloro-6-(trichloromethyl)pyridine) which is the active ingredient in N-Serve (trademark, Dow Chemical Co.), and dicyandiamide (DCD).

The objectives of this study were to determine the effects of N sources, rates, and NI effects on dry matter yield, N concentration, and N uptake on bermudagrass forage production in Southeastern Oklahoma.

CHAPTER II

LITERATURE REVIEW

The chief objective of forage fertilization is to produce maximum yield of acceptable quality forage with least cost. For this reason, much research has concentrated on sulfur coated urea (SCU), the least expensive slow release nitrogen (SRN). The potential benefits from SRN fertilizers include (i) more efficient use of N by the crop, (ii) less leaching of N, (iii) lower NH_4^+ toxicity, (iv) longer lasting N supply, (v) reduced volatilization losses of N, and (vi) lower application cost (Allen, 1984).

The principle behind the use of SCU is to limit losses due to hydrolysis to only that portion dissolved and leaching to the portion nitrified. With forage crops, early clippings often contain more N than is actually required for optimum growth. Thus, luxury consumption of N can also be reduced to supply N in accordance with normal crop requirements (Allen and Mays, 1971).

The same authors conducted a greenhouse pot experiment using urea (Ur) and SCU mixed with the soil prior to seeding common bermudagrass (*Cynodon dactylon* L.). At the higher rate of N (500 and 1000 mg N/pot), yield of forage from SCU was greater than from Ur. Since early clippings had very high N contents, it is assumed that luxury uptake of N from Ur occurred at the 1000 mg rate of application.

Allen et al. (1978) concluded that SCU increased yields over Ur and ammonium nitrate (AN) in a soil column experiment. Their results support the premise that slow-release fertilizers supply more N for crop response, but may not reduce leaching losses. Hummel and Waddington (1981), also reported that N recovery was highest with SCU in an evaluation of slow-release N sources for maintenance fertilization of Kentucky bluegrass (*Poa pratensis* L.) turf.

Research has shown that inhibition of nitrification can be achieved through the application of chemicals. The most widely researched chemical is 2-chloro-6-(trichloromethyl)pyridine commonly known as nitrapyrin, and the active ingredient in N-Serve (trademark of the Dow Chemical Co., Midland, Mich.). Under controlled conditions in laboratory and greenhouse research, this chemical has been shown to inhibit nitrification (Onken, 1980). Bundy and Bremner (1973) surveyed several nitrification inhibitors (NIs) in laboratory experiments and reported that they were most effective on coarse-textured soils with low organic matter content. They also showed that temperature influenced the relative effectiveness of nitrification inhibition, with NIs being much more effective at 15 than at 30°C. Nitrification inhibitors should be viewed as a management tool. The benefit to be derived depends on the soil type, time and rate of N application, and weather conditions between the time the N is applied and absorbed by the crop (Hoeft, 1984). Because NI performance is dependent upon the aforementioned parameters, the literature contains varying results of their effectiveness.

According to Varsa et al. (1984) nitrapyrin was effective in suppressing nitrification of Ur and UAN up to 182 days following fall preplant application to winter wheat (*Triticum aestivum* L.) in southern Illinois. This response occurred under wet soil conditions and much below normal temperatures for the winter. In a separate experiment where mild temperatures occurred through November, results showed a rapid decline in inhibitor effectiveness. Greatest responses to NI use were always associated with soil and seasonal conditions that favored N losses during the winter and early spring. Frye et al. (1981) studied the effectiveness of nitrapyrin on yield of no-tillage corn (*Zea mays* L.) in Kentucky, on soils that tended to be wet in the spring. Because nitrapyrin is volatile, the manufacturer recommends incorporation into the soil immediately after application. This study was conducted to determine the effectiveness of AN and Ur broadcast, unincorporated, and nitrapyrin sprayed onto the granules. Yields of corn were generally increased as a result of the nitrapyrin where N was applied at a yield-limiting rate. Touchton et al. (1979) conducted studies at the University of Illinois on nitrification and corn yield. Nitrapyrin was mixed with Ur at a relatively high rate (2.24 kg a.i. ha^{-1}) prior to application, broadcast on the soil surface, and incorporated by disking. Nitrification of Ur applied 15 October was complete by 23 March. However, when nitrapyrin was added to the 67 and 134 kg N ha^{-1} rates, 97% and 47% respectively, of the ammonium (NH_4^+) -N was recovered from the top 15 cm of the soil by this date. Nitrapyrin added with fall applied Ur at 67 kg N ha^{-1} increased yield 27% over fall applied urea without the NI. There was no yield advantage in applying nitrapyrin with 134 kg N ha^{-1} in the fall. Generally, when soil and climatic factors do not favor N losses due to denitrification and leaching after applications, NIs do not provide adequate inhibition of nitrification.

Working in Georgia, Boswell et al. (1976) showed that nitrapyrin had no effect on winter wheat yield. This was evident each year of the study where no differences in yield occurred between the fall applied 28 kg N ha^{-1} rate and the 84 kg N ha^{-1} of ammonium sulfate (AS) with or without nitrapyrin. Likewise, tissue N levels were not affected by the addition of the NI to 84 kg N ha^{-1}. Nitrapyrin delayed nitrification in the surface 15 cm of soil at the January sampling (2 to 3 months after fall N application) but not until March. Westerman et al. (1981) reported that soil N forms were altered in a study to evaluate the effects of NIs on soil N forms and yield of grain sorghum [*Sorghum bicolor* (L.) Moench]. The effect of altered soil N forms by nitrapyrin did not result in increased yields in Oklahoma. This was attributed to minimal losses of N via leaching and denitrification, and/or excessive dilution of the inhibitors in soil with broadcast incorporated application of N.

Because of its high vapor pressure, nitrapyrin cannot be granulated with solid N fertilizer without loss of the inhibitor during processing, storage, and handling. Volatilization losses of nitrapyrin are also a problem when using with solid fertilizers such as urea. The inhibitor must be sprayed on the urea and the large surface area of the granules allows rapid inhibitor volatilization. For this reason there is interest in using dicyandiamide (DCD) as a NI (Hauck, 1984). The high melting point of DCD (211°C) and resultant lower vapor pressure compared with nitrapyrin makes it possible to incorporate into granular urea during the fertilizer manufacturing process. In addition, DCD contains substantial amounts of N (66.6%) which will be used to some extent by the crop after inhibitor breakdown in the soil (Gautney et al., 1983). According to Amberger (1981), DCD inhibits the first step of nitrification, the oxidation of ammonium by *Nitrosomonas* bacteria. This effect of DCD is bacteriostatical (not bactericidal) and specific for *Nitrosomonas*.

Reddy (1964) reported that in a series of laboratory experiments, DCD inhibited nitrification of AS at all rates utilized. An increase in the rate of DCD applied resulted in an increase in the NH_4^+-N present in the soil and a decrease in the rate of nitrate (NO_3^-) formation. Reddy also found that decomposition of DCD was more rapid in fine-textured sandy-loam soil containing relatively more organic matter than in a coarse-textured and low organic matter sandy soil. He concludes that the influence of organic matter on the decomposition of DCD may be attributed to the increased activity of soil microorganisms which decompose DCD and convert it to ammonium nitrogen. In their previously mentioned study, Bundy and Bremner (1973) likewise found that the NIs tested were more effective in a soil of 55% sand, 21% clay than on two other soils which were < 29% sand and > 33% clay. Among the other NIs studied, nitrapyrin and DCD were applied with AS and Ur. With both N sources nitrapyrin proved to inhibit nitrification considerably longer than DCD in all soils at both 15 and 30°C. Nitrapyrin was also more effective with Ur than AS as a NI, which was not the case with DCD. Vilsmeier (1981), reports that soil temperature determines the turnover rate or decomposition of DCD to a large extent. An increase of soil temperature up to 25°C accelerates the turnover of DCD to such a degree that after 35 days no more than 10% of the original amount of DCD can be detected (Vilsmeier, 1981).

Randall and Malzer (1981) conducted a field study in south central Minnesota to determine the effect of DCD applied with AS and Ur on (i) the rate of nitrification, (ii) the N uptake by corn, and (iii) the yield of corn on poorly drained soils. The data indicate that nitrification of AS and Ur was delayed for about 9 weeks after application 9 May 1981. Under the environmental conditions prevailing during 1981, the spring application of AS and Ur with DCD did not appear to influence corn production over treatments which did not receive DCD. Rainfall amounts in the two-month period following N application were less than normal. Thus, denitrification losses did not occur and a crop response to the inhibitor would not have been expected. Working with Kentucky bluegrass turf in north-central Indiana, Mosdell et al. (1986) conducted a study utilizing DCD as a NI. Nitrogen sources included Ur and AS with and without 10% DCD-N. Although DCD inhibited nitrification for a short period at a 98 kg N ha^{-1} rate applied twice during the growing season, except for slightly higher visual quality, it did not improve turf response to soluble N applications over 3 years. They postulated that leaching of NO_3^- was not a significant problem, and periods conducive to denitrification occurred long after DCD applications when NO_3^- concentrations were similar between DCD-amended fertilizers, Ur, and AS. Thus, they concluded DCD may prevent NO_3^- losses 2 to 3 weeks, however, this short period of effectiveness would not warrant its use as an inhibitor in turf N programs at application rates of less than 14.6 kg ha^{-1}. Touchton (1981) conducted a study to determine the effect of DCD on nitrification of Ur-N, wheat growth, and grain yield on the coastal plains of central Alabama. The data from this study do not provide strong support for using DCD-treated Ur as a N source for winter wheat. The 1981 growing season, however, was drier than normal and the control of nitrification by DCD at 4 to 6 weeks after application may have made a difference in yield in a year with normal rainfall patterns.

Economic conditions are forcing reexamination of conventional N fertilizer rather than development of new kinds of N fertilizer. The high analysis and associated savings in long distance transportation have promoted urea as a world commodity (Russel, 1984). Westerman et al. (1983) stated that because of increased emphasis on use of high analysis fertilizer and the increased fuel costs of anhydrous ammonia (AA) applications in grass sod, further investigation of the efficiency of applied Ur is warranted for bermudagrass forage production. Bermudagrass has a high nitrogen requirement for forage production. According to Johnson and Rommann (1983), 263.2 kg N ha^{-1} should be available if the yield goal is 8.93 Mg ha^{-1} dry matter bermudagrass forage with 10% dry crude protein. For these reasons it is important to determine the most efficient source of N to be utilized.

Hill and Tucker (1968) reported there were no differences in dry matter of all clippings of bermudagrass due to Ur, AA, and AN at lower rates. At higher rates of N application, AA yields in the first clipping were lower. This was attributed to sod burn. Anderson and Kunkel (1983) studied the effects of various N sources on yield and N uptake of bermudagrass to determine the effectiveness of Ur in the field as a nitrogen fertilizer. Urea and UAN appeared to perform as well as, and in some cases significantly better than, AN in terms of yield production of the three bermudagrass varieties tested.

Recently there has been renewed interest in altering NH_4^+/NO_3^- ratios to increase crop growth. Although this is a very complex issue, as described by Hageman (1980), controlled solution culture studies reported in the literature indicate a physiological basis for greater plant growth with NO_3^- and NH_4^+ combined than with either NO_3^- or NH_4^+ alone (Bock, 1986). In greenhouse experiments with spring wheat and grain sorghum, Bock (1986) reported that higher NH_4^+/NO_3^- ratios than typically found in the field were required to maximize yield, and significantly higher rates of supplemental NH_4^+ than required for maximum yield did not reduce yield below the maximum. Several N management variables can be manipulated to control NH_4^+/NO_3^- ratios. Nitrification inhibitors may be instrumental in altering soil N-forms to achieve higher NH_4^+ levels.

CHAPTER III

MATERIALS AND METHODS

In 1985 a fertility study was initiated on an established sward of Midland bermudagrass (*Cynodon dactylon* L.) at the Wes Watkins Agricultural Research and Extension Center in Lane, Oklahoma on a Bernow fine sandy loam (Glossic Paleudalf). Prior to the initiation of the study, soil samples (0 to 15 cm depth) were taken 1 May 1985 and a composite sample analyzed to determine the initial soil characteristics. Routine soil analysis, as described by Hanlon and Johnson (1983), for pH, buffer index, NO_3^--N, phosphorus, and potassium were 5.0, 6.9, 4 kg N ha^{-1}, 57 kg P ha^{-1}, and 122 kg K ha^{-1}, respectively. This field study was conducted for two consecutive years using four N sources: ammonium nitrate (AN, 34-0-0), urea (Ur, 46-0-0), sulfur coated urea (SCU, 36-0-0), and urea ammonium nitrate solution (UAN, 28-0-0), plus Ur and UAN mixed with nitrapyrin (2-chloro-6-(trichloromethyl)pyridine), and Ur impregnated with dicyandiamide (DCD, with 10% N as DCD). The labeled rate of 0.56 kg a.i. ha^{-1} nitrapyrin tradename N-Serve (NS) was mixed with Ur and UAN (N-Serve 24 and 24E respectively). Nitrogen sources with and without nitrification inhibitors (NIs) were applied at rates of 0, 112, 224, and 448 kg N ha^{-1} annually in the spring. Treatments were placed in a factorial arrangement of N sources and rates in a randomized complete block design including a check plot in each of the four replications. Nitrogen sources were broadcast on individual plots measuring 15.25 X 6.1 m using a 2.44 m Barber fertilizer spreader calibrated for proper N rates, with the exception of treatments using UAN which were surface applied at specified N rates using a 3-point hydraulic sprayer. Fertilizer treatments were applied 4 June 1985 and 14 May 1986. Soil tests showed a potassium deficiency, so 67.2 kg K_2O ha^{-1} (0-0-62) was applied 24 May 1985 and 13 May 1986 to the entire study area.

Chemical applications of atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-S-triazine) at a rate of 1.68 kg a.i. ha^{-1} were applied 24 May 1985 and 15 April 1986. On 1 August 1985, 2,4-D (((2,4-dichlorophenoxy) acetic acid) dimethylamine) was applied at a rate of 1.12 kg a.i. ha^{-1} for weed control. The herbicides were applied with a carrier volume of 275 L ha^{-1} at a speed of 6 km ha^{-1} using a 3-point hydraulic sprayer.

Because of limited rainfall (Table 1) only two harvests were obtained in 1985 (16 July, 16 October) and 1986 (26 June, 18 October). Forage was cut when approximately 30 cm tall using a 2.13 m Sperry-New Holland haybine mower conditioner. A 2.13 X 3.05 m area from the middle of each plot was weighed to obtain a field plot weight. A representative moisture sample was taken from each plot, weighed, oven dried at 60°C for 48 h, then reweighed. Field plot weights were then adjusted to report dry matter yields (Mg ha^{-1}). Remaining forage was cut, bailed, and removed from the experimental area after each harvest. Dried samples were ground with a Wiley Mill to pass a 1 mm sieve. Total N was determined colorimetrically from Kjeldahl digestion using a Technicon Autoanalyzer II. Nitrogen uptake was calculated as a function of dry matter yield and N content of the tissue. Appropriate analysis of variance were obtained for pooled data over years using TurboStat (Nofziger et al., 1986) and all other analysis using general linear models procedures outlined by the SAS Institute (Statistical Analysis Systems Staff, 1985).

Table 1. Precipitation during 1985 and 1986.

	Year	
Month	1985	1986
	------- cm	-------
January	5.3	0.2
February	7.5	9.4
March	14.6	7.0
April	25.6	15.9
May	10.4	17.9
June	14.2	13.4
July	9.1	0.7
August	4.3	5.4
September	8.2	22.0
October	15.9	6.9
November	12.9	14.2
December	1.1	1.7
First harvest[a]	22.5	23.7
Second harvest[b]	16.0	33.2
Total (year)	130.1	114.6

[a] Total amount of rainfall from initial fertilization until first harvest.

[b] Total amount of rainfall from first harvest until second harvest.

CHAPTER IV

RESULTS AND DISCUSSION

First Harvest 1985

Dry Matter Yield

Results of the analysis of variance (ANOVA) show that there were no differences among N sources, although N rate did show a significant F ratio. From Table 2, the linear effect of increasing rates was also significant at the 5% level of probability. The means of all sources in Table 3 show the increases in yield of 5.07, 6.68, and 7.18 Mg ha^{-1} for N rates of 112, 224, and 448 kg N ha^{-1}, respectively. The average for the check was 6.09 Mg ha^{-1}, which, when compared to the response of the three rates, does not show an adequate increase in yield due to rates of fertilizer applied to be of agronomic importance. This represents only an increase of 1.09 Mg ha^{-1} with the addition of 448 kg N ha^{-1}. Variability in yield response was high as can be seen from a coefficient of variation (CV) of 51.8% and standard deviation (SD) of 3.26 Mg ha^{-1} (Table 2).

Tissue Nitrogen Concentration

Treatment effects as well as check vs. all other treatments were highly significant for tissue N concentration (Table 4). Sources without NIs were significant at the 1% level also. Figure 1 represents the response of tissue N concentration to the sources without NIs that had significant differences among themselves and the mean of all sources with NIs added. Data was represented in this fashion according to the ANOVA results. Note from Table 4 that there was no significant difference among sources with NIs. Therefore, it is assumed that the mean is representative of the all sources with NIs added. The LSD given for "Among sources w/o NI" in Fig. 1 is the value to detect any differences among the four sources without NIs. The LSD shown for "Between w/ & w/o NI" in Fig. 1 is the value to determine differences between any of the four sources without NIs and the mean N concentration produced by all sources with NIs added. All other bar charts will be constructed in the same manner. Figure 1 and Table 5 show this response to N sources, with ammonium nitrate (AN) and urea (UR) producing tissue N concentrations greater than all other sources including those with NIs added. Nitrogen rates produced significant variation with the linear response significant at the 1% level (Table 4). Figure 2 shows the linear increase to the N rates applied.

Table 2. Analysis of variance for first harvest dry matter yield, 1985.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	19.358	6.453	0.61
Treatment	21	172.942	8.235	0.77
Source w/o NI	3	10.074	3.358	0.32
Source w/ NI	2	2.646	1.323	0.12
Source w/o NI vs. Source w/ NI	1	1.922	1.922	0.18
Rate (All Sources)	2	67.764	33.882	3.19*
Linear	1	61.992	61.992	5.83*
Quadratic	1	5.772	5.772	0.54
Source w/o NI x Rate	6	57.166	9.528	0.90
Source w/ NI x Rate	4	8.603	2.151	0.20
Source w/o NI vs. Source w/ NI x Rate	2	24.580	12.290	1.16
Check vs. Others	1	0.187	0.187	0.02
Error	63	669.723	10.631	
Total	87	862.0243		

* Significant at the 0.05 probability level.
CV = 51.8%, SD = 3.26 Mg ha^{-1}.

Table 3. First harvest dry matter yield, 1985.

N Source	0	112	224	448	Mean
	N Rate (kg N ha^{-1})				
	Mg ha^{-1}				
Without NI					
AN	.	5.91	4.85	8.34	6.37
UR	.	4.81	7.88	7.83	6.84
SCU	.	3.51	7.04	6.86	5.80
UAN	.	3.04	8.44	5.64	5.71
Mean		4.32	7.05	7.17	6.18
With NI					
UR/DCD	.	6.91	6.15	7.33	6.80
UR/NS	.	5.53	6.59	6.28	6.13
UAN/NS	.	5.80	5.81	7.96	6.52
Mean		6.08	6.18	7.19	6.48
All Sources	.	5.07	6.68	7.18	6.31
Check	6.09				

Table 4. Analysis of variance for first harvest tissue N concentration, 1985.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	145.776	48.592	2.79*
Treatment	21	1528.005	72.762	4.18**
Source w/o NI	3	270.601	90.200	5.18**
Source w/ NI	2	23.555	11.778	0.68
Source w/o NI vs. Source w/ NI	1	44.390	44.390	2.55
Rate (All Sources)	2	721.190	360.595	20.71**
Linear	1	668.404	668.404	38.40**
Quadratic	1	52.786	52.786	3.03
Source w/o NI x Rate	6	214.310	35.718	2.05
Source w/ NI x Rate	4	25.791	6.448	0.37
Source w/o NI vs. Source w/ NI x Rate	2	88.478	44.239	2.54
Check vs. Others	1	139.689	139.689	8.02**
Error	63	1096.729	17.408	
Total	87	2770.510		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
CV = 18.8%, SD = 4.2 g N kg^{-1}.

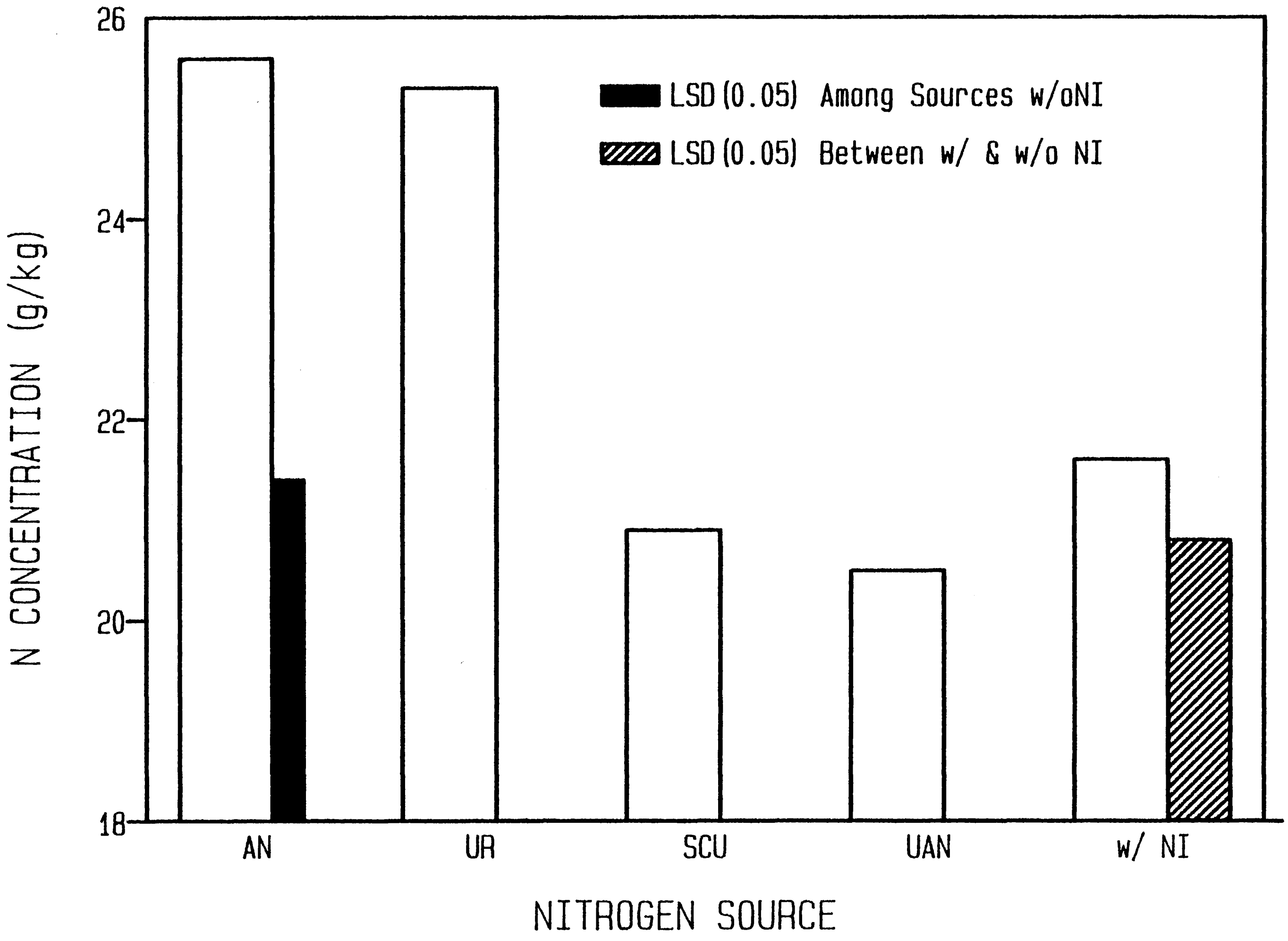

Fig. 1. Nitrogen concentration in first harvest tissue as affected by N sources, 1985.

Table 5. First harvest tissue N concentration, 1985.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	g N kg^{-1}				
Without NI					
AN	.	22.4	23.8	30.6	25.6
UR	.	26.3	21.1	28.4	25.3
SCU	.	18.7	17.3	26.7	20.9
UAN	.	13.4	21.2	26.9	20.5
		Mean			
		20.2	20.8	28.2	23.1
With NI					
UR/DCD	.	20.6	23.9	23.7	22.7
UR/NS	.	17.7	21.6	24.5	21.2
UAN/NS	.	17.7	20.4	24.4	20.8
		Mean			
		18.7	22.0	24.2	21.6
All Sources	.	19.5	21.3	26.5	22.4
Check	16.4				

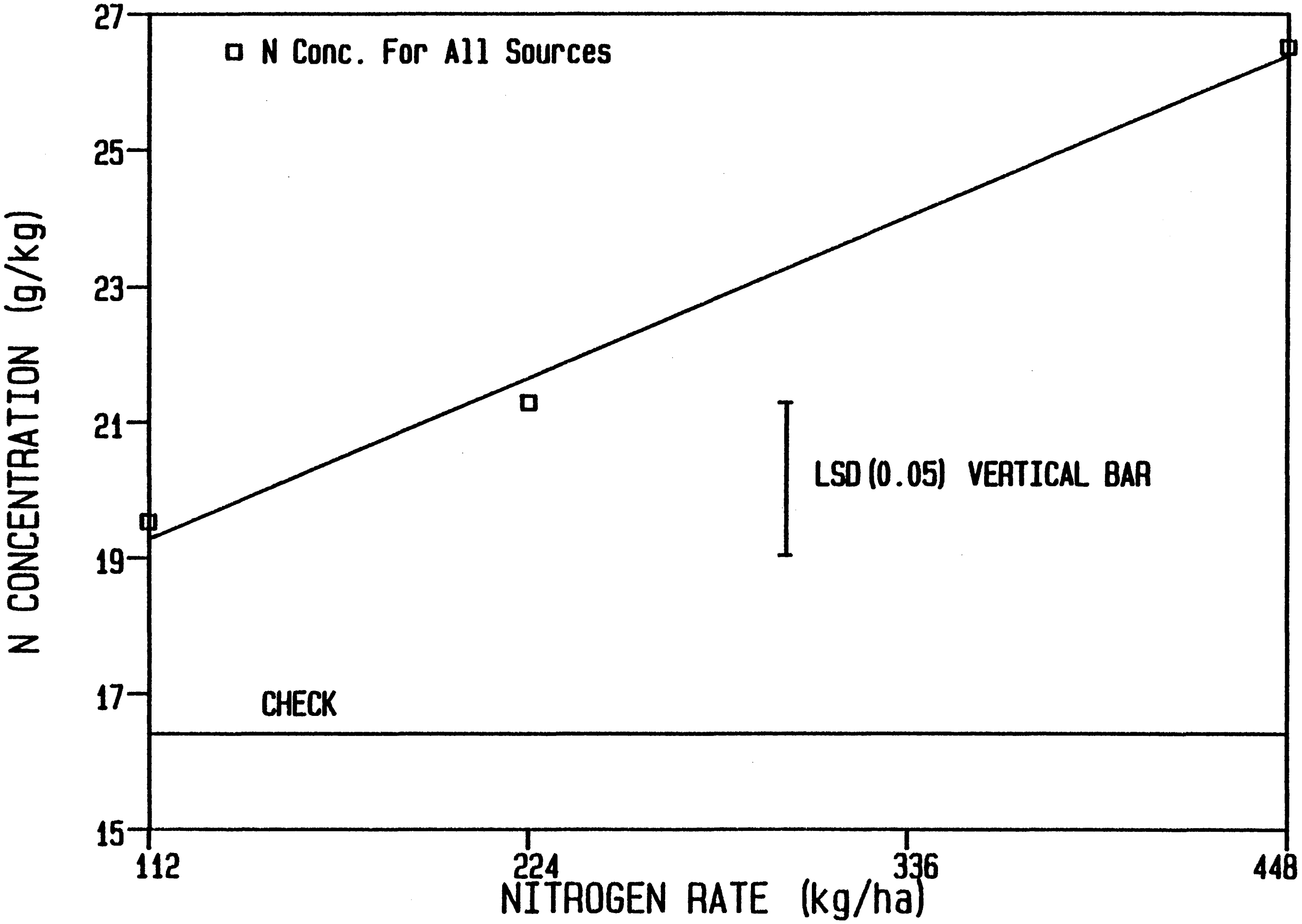

Fig. 2. Linear response of N concentration in first harvest tissue to increasing N rates, 1985.

Nitrogen Uptake in Forage

Nitrogen uptake being a function of both yield and N concentration reflects both of these responses. Treatment effects were significant as well as response to increasing N rates (Table 6). The effect of N rates was to increase N uptake in a linear fashion. Sources did not differ in the N yield produced (Table 6), although, AN and Ur did show a greater response than other N sources (Table 7).

Table 6. Analysis of variance for first harvest N uptake in forage, 1985.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	4096.253	1365.418	0.30
Treatment	21	172643.578	8221.123	1.78*
Source w/o NI	3	24797.432	8265.811	1.79
Source w/ NI	2	3742.455	1871.227	0.41
Source w/o NI vs. Source w/ NI	1	206.986	206.986	0.04
Rate (All Sources)	2	97563.228	48781.614	10.59**
Linear	1	97560.037	97560.037	21.18**
Quadratic	1	3.191	3.191	0.00
Source w/o NI x Rate	6	30378.674	5063.112	1.10
Source w/ NI x Rate	4	5151.689	1287.922	0.28
Source w/o NI vs. Source w/ NI x Rate	2	6059.503	3029.751	0.66
Check vs. Others	1	4743.612	4743.611	1.03
Error	63	290190.686	4606.201	
Total	87	466930.518		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
CV = 49.2%, SD = 68 kg N ha^{-1}.

Table 7. First harvest uptake of N in forage, 1985.

N Source	N Rate (kg N ha^{-1}) 0	112	224	448	Mean
	kg N ha^{-1}				
Without NI					
AN	.	132	115	255	167
UR	.	127	166	222	172
SCU	.	66	122	183	124
UAN	.	41	179	152	124
Mean		92	146	203	147
With NI					
UR/DCD	.	142	147	174	154
UR/NS	.	98	142	154	131
UAN/NS	.	103	119	194	139
Mean		114	136	174	141
All Sources	.	101	141	191	144
Check	100				

Second Harvest 1985

The ANOVA for all three response variables showed no significant differences at the 5% level of detection (Tables 8, 10, and 12). Neither dry matter yield, N concentration, or N uptake differed appreciably from the check (Tables 9, 11, and 13). Nitrogen fertilization in the spring did not affect bermudagrass forage production in the second harvest.

Table 8. Analysis of variance for second harvest dry matter yield, 1985.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	11.457	3.819	2.38
Treatment	21	28.346	1.350	0.84
Source w/o NI	3	3.766	1.255	0.78
Source w/ NI	2	0.174	0.087	0.05
Source w/o NI vs. Source w/ NI	1	1.173	1.173	0.73
Rate (All Sources)	2	7.767	3.884	2.42
Linear	1	4.109	4.109	2.56
Quadratic	1	3.658	3.658	2.28
Source w/o NI x Rate	6	10.346	1.724	1.07
Source w/ NI x Rate	4	4.487	1.122	0.70
Source w/o NI vs. Source w/ NI x Rate	2	0.574	0.287	0.18
Check vs. Others	1	0.059	0.059	0.04
Error	63	101.185	1.606	
Total	87	140.989		

CV = 54.3%, SD = 1.27 Mg ha^{-1}.

Table 9. Second harvest dry matter yield, 1985.

N Source	N Rate (kg N ha^{-1}) 0	112	224	448	Mean
	Mg ha^{-1}				
Without NI					
AN	.	2.47	2.61	1.90	2.32
UR	.	1.64	2.14	2.17	1.98
SCU	.	1.68	1.62	2.67	1.99
UAN	.	1.35	3.52	3.11	2.66
Mean		1.78	2.47	2.46	2.24
With NI					
UR/DCD	.	2.18	2.16	2.80	2.38
UR/NS	.	1.80	3.45	2.28	2.51
UAN/NS	.	2.34	2.96	2.32	2.54
Mean		2.11	2.85	2.47	2.48
All Sources	.	1.92	2.63	2.46	2.34
Check	2.22				

Table 10. Analysis of variance for second harvest tissue N concentration, 1985.

Source	df		Sum of Squares	Mean Square	*F*
Block	3		60.727	20.242	2.51
Treatment	21		110.066	5.241	0.65
Source w/o NI	3		22.756	7.585	0.94
Source w/ NI	2		12.549	6.274	0.78
Source w/o NI vs. Source w/ NI	1		4.015	4.015	0.50
Rate (All Sources)	2		14.854	7.427	0.92
Linear		1	5.240	5.240	0.65
Quadratic		1	9.615	9.615	1.19
Source w/o NI x Rate	6		32.280	5.380	0.67
Source w/ NI x Rate	4		11.705	2.926	0.36
Source w/o NI vs. Source w/ NI x Rate	2		2.820	1.410	0.18
Check vs. Others	1		9.087	9.087	1.13
Error	63		507.094	8.049	
Total	87		677.888		

CV = 23.1%, SD = 2.8 g N kg^{-1}.

Table 11. Second harvest tissue N concentration, 1985.

N Source	N Rate (kg N ha^{-1}) 0	112	224	448	Mean
	g N kg^{-1}				
Without NI					
AN	.	12.4	11.8	12.6	12.3
UR	.	13.0	10.6	11.8	11.8
SCU	.	12.5	12.3	12.2	12.3
UAN	.	12.4	12.5	16.0	13.7
Mean		12.6	11.8	13.2	12.5
With NI					
UR/DCD	.	11.5	11.7	11.8	11.6
UR/NS	.	12.0	12.4	14.4	12.9
UAN/NS	.	12.1	11.6	11.3	11.7
Mean		11.9	11.9	12.5	12.1
All Sources	.	12.3	11.9	12.9	12.3
Check	10.8				

Table 12. Analysis of variance for second harvest N uptake in forage, 1985.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	1137.075	379.025	1.02
Treatment	21	7287.543	347.026	0.93
Source w/o NI	3	2138.814	712.938	1.91
Source w/ NI	2	182.186	91.093	0.24
Source w/o NI vs. Source w/ NI	1	33.560	33.560	0.09
Rate (All Sources)	2	1676.304	838.152	2.25
Linear	1	1179.430	1179.430	3.17
Quadratic	1	496.874	496.874	1.33
Source w/o NI x Rate	6	2392.648	398.775	1.07
Source w/ NI x Rate	4	705.664	176.416	0.47
Source w/o NI vs. Source w/ NI x Rate	2	34.651	17.326	0.05
Check vs. Others	1	123.716	123.716	0.33
Error	63	23462.299	372.417	
Total	87	31886.917		

CV = 66.4%, SD = 19 kg N ha^{-1}.

Table 13. Second harvest uptake of N in forage, 1985.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	kg N ha^{-1}				
Without NI					
AN	.	31	31	24	29
UR	.	21	23	26	23
SCU	.	21	20	33	25
UAN	.	17	44	50	37
Mean		23	30	33	29
With NI					
UR/DCD	.	25	25	33	28
UR/NS	.	22	43	33	33
UAN/NS	.	28	34	26	29
Mean		25	34	31	30
All Sources	.	24	31	32	29
Check	24				

Harvest Totals For 1985

Dry Matter Yield

Results of first and second harvest were summed to determine total dry matter yield. The corresponding ANOVA (Table 14) shows that in 1985 N sources did not significantly influence yield, but N rates did. The result of increasing N rate was a linear increase in dry matter yield (Table 14). Although all rates increased yield over those obtained from the check, with the exception of sources applied at 112 kg N ha^{-1} (Table 15), this data does not show a significant increase in yield large enough to warrant these fertilizer N additions. Especially when one considers that the CV is 40.8% and SD is 3.52 Mg ha^{-1} (Table 14).

Nitrogen Uptake in Forage

Nitrogen sources did not significantly influence N uptake in the forage, while N rates did (Table 16). The linear response is evident from the ANOVA (Table 16) and means of the N rates applied (Table 17).

Table 14. Analysis of variance for total dry matter yield summed over the first and second harvest, 1985.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	15.303	5.101	0.41
Treatment	21	255.117	12.148	0.98
Source w/o NI	3	7.620	2.540	0.21
Source w/ NI	2	1.861	0.931	0.08
Source w/o NI vs. Source w/ NI	1	6.085	6.085	0.49
Rate (All Sources)	2	116.650	58.325	4.71*
Linear	1	98.050	98.050	7.91**
Quadratic	1	18.600	18.600	1.50
Source w/o NI x Rate	6	79.055	13.176	1.06
Source w/ NI x Rate	4	18.040	4.510	0.36
Source w/o NI vs. Source w/ NI x Rate	2	25.350	12.675	1.02
Check vs. Others	1	0.456	0.456	0.04
Error	63	780.498	12.389	
Total	87	1050.918		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
CV = 40.8%, SD = 3.52 Mg ha^{-1}.

Table 15. Total dry matter yield summed over the first and second harvest, 1985.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	Mg ha^{-1}				
Without NI					
AN	.	8.38	7.45	10.23	8.67
UR	.	6.45	10.01	10.01	8.82
SCU	.	5.18	8.66	9.53	7.79
UAN	.	4.39	11.97	8.74	8.37
Mean		6.10	9.52	9.63	8.42
With NI					
UR/DCD	.	9.09	8.31	10.13	9.17
UR/NS	.	7.33	10.04	8.56	8.64
UAN/NS	.	8.14	8.77	10.28	9.06
Mean		8.18	9.04	9.65	8.96
All Sources	.	6.99	9.31	9.64	8.65
Check	8.30				

Table 16. Analysis of variance for total N uptake in forage summed over the first and second harvest, 1985.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	1762.271	587.424	0.12
Treatment	21	202253.327	9631.111	2.00*
Source w/o NI	3	19896.540	6632.180	1.38
Source w/ NI	2	2431.382	1215.691	0.25
Source w/o NI vs. Source w/ NI	1	74.687	74.687	0.02
Rate (All Sources)	2	120739.214	60369.607	12.54**
Linear	1	120160.565	120160.565	24.96**
Quadratic	1	578.649	578.649	0.12
Source w/o NI x Rate	6	41086.542	6847.757	1.42
Source w/ NI x Rate	4	4887.309	1221.827	0.25
Source w/o NI vs. Source w/ NI x Rate	2	6733.482	3366.741	0.70
Check vs. Others	1	6404.171	6404.171	1.33
Error	63	303232.838	4813.220	
Total	87	507248.436		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
CV = 41.6, SD = 69 kg N ha^{-1}.

Table 17. Total N uptake in forage summed over the first and second harvest, 1985.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	kg N ha^{-1}				
Without NI					
AN	.	163	146	279	196
UR	.	148	189	248	195
SCU	.	87	142	216	149
UAN	.	58	223	202	164
Mean		115	176	236	176
With NI					
UR/DCD	.	167	172	207	182
UR/NS	.	120	185	187	164
UAN/NS	.	131	153	220	168
Mean		139	170	205	171
All Sources	.	125	173	223	174
Check	124				

First Harvest 1986

Dry Matter Yield

From the ANOVA (Table 18) none of the treatment effects were significant at the 5% level of detection. From data presented in Table 19, even sources applied at 448 kg N ha^{-1} did not appreciably increase yield over that obtained from the check.

Table 18. Analysis of variance for first harvest dry matter yield, 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	4.804	1.601	0.39
Treatment	21	67.304	3.205	0.78
Source w/o NI	3	7.732	2.577	0.63
Source w/ NI	2	23.646	11.823	2.88
Source w/o NI vs. Source w/ NI	1	2.843	2.843	0.69
Rate (All Sources)	2	6.056	3.028	0.74
Linear	1	4.891	4.891	1.19
Quadratic	1	1.165	1.165	0.28
Source w/o NI x Rate	6	3.621	0.604	0.15
Source w/ NI x Rate	4	7.503	1.876	0.46
Source w/o NI vs. Source w/ NI x Rate	2	15.270	7.635	1.86
Check vs. Others	1	0.633	0.633	0.15
Error	63	258.357	4.101	
Total	87	330.465		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
CV = 41.6%, SD = 2.03 Mg ha^{-1}.

Table 19. First harvest dry matter yield, 1986.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	Mg ha^{-1}				
Without NI					
AN	.	4.48	5.18	4.47	4.71
UR	.	3.92	5.17	4.76	4.61
SCU	.	4.89	6.49	4.70	5.36
UAN	.	4.14	4.55	4.05	4.25
Mean		4.35	5.35	4.49	4.73
With NI					
UR/DCD	.	5.15	6.22	7.38	6.25
UR/NS	.	4.96	3.99	4.80	4.58
UAN/NS	.	4.07	3.80	5.59	4.48
Mean		4.73	4.67	5.92	5.10
All Sources	.	4.51	5.06	5.11	4.89
Check	4.49				

Tissue Nitrogen Concentration

Nitrogen concentration in the tissue was significantly affected by the addition of N (Table 20). With the check producing 12.5 g N kg^{-1} in the tissue compared to a grand mean of 18.4 g N kg^{-1} produced by fertilization (Table 21). There was also a difference in the response between those sources without NIs and sources with NIs (Table 20), although no significant differences occurred among either sources with or without NIs. Table 21 shows that sources without NIs produced a greater N concentration in the tissue than those with a NI added. Although rate was significant as a linear response (Table 20), no definite increases occur between the 112 and 224 kg N ha^{-1} rates. Over all sources the 448 kg N ha^{-1} did appear to increase the concentration of N in tissue (Table 21). The significant interaction of sources without NIs vs. sources with by rate can be seen graphically in Fig. 3.

Table 20. Analysis of variance for first harvest tissue N concentration, 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	53.441	17.814	1.09
Treatment	21	604.497	28.786	1.75*
Source w/o NI	3	4.727	1.576	0.10
Source w/ NI	2	13.781	6.890	0.42
Source w/o NI vs. Source w/ NI	1	48.046	48.046	2.93*
Rate (All Sources)	2	129.484	64.742	3.95*
Linear	1	113.630	113.630	6.92*
Quadratic	1	15.855	15.855	0.97
Source w/o NI x Rate	6	18.588	3.098	0.19
Source w/ NI x Rate	4	91.893	22.973	1.40
Source w/o NI vs. Source w/ NI x Rate	2	162.263	81.131	4.94*
Check vs. Others	1	135.715	135.715	8.27**
Error	63	1033.862	16.411	
Total	87	1691.800		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
CV = 22.3%, SD = 4.1 g N kg^{-1}.

Table 21. First harvest tissue N concentration, 1986.

N Source	0	112	224	448	Mean
			N Rate (kg N ha^{-1})		
			g N kg^{-1}		
Without NI					
AN	.	18.6	17.0	23.2	19.6
UR	.	17.5	17.5	21.1	18.7
SCU	.	18.8	16.1	22.2	19.0
UAN	.	16.9	17.3	22.6	19.0
				Mean	
		17.9	17.0	22.3	19.1
With NI					
UR_DCD	.	19.5	19.6	15.4	18.2
UR_NS	.	14.2	19.9	19.2	17.8
UAN_NS	.	15.6	17.2	17.3	19.7
				Mean	
		16.4	18.9	17.3	17.5
All Sources	.	17.3	17.8	20.1	18.4
Check	12.5				

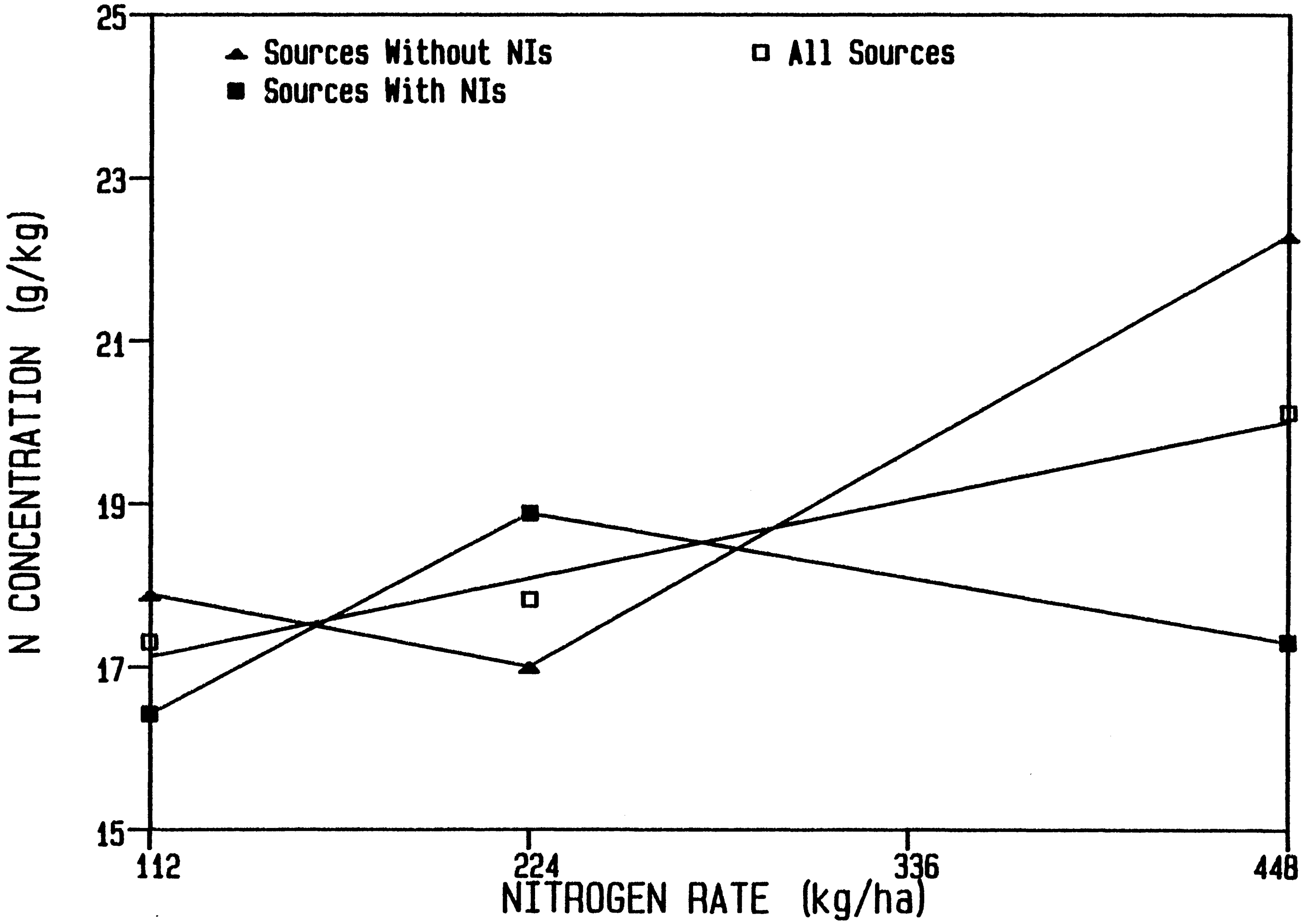

Fig. 3. Linear response of N concentration in tissue to increasing N rates in the first harvest, 1986.

Nitrogen Uptake in Forage

Response of N uptake differed significantly among sources with NIs added (Table 22). Urea with DCD produced greater N yield in forage than other sources with NIs (Table 23), and sources without NIs (Fig. 4). Nitrogen rates showed a linear response, although the main effect due to rates was not significant (Table 22).

Table 22. Analysis of variance for first harvest N uptake in forage, 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	1168.398	389.466	0.39
Treatment	21	24276.180	1156.009	1.16
Source w/o NI	3	5480.704	1826.901	1.84
Source w/ NI	2	7051.600	3525.800	3.55*
Source w/o NI vs. Source w/ NI	1	1.540	1.540	0.00
Rate (All Sources)	2	5571.834	2785.917	2.80
Linear	1	5507.559	5507.559	5.54*
Quadratic	1	64.275	64.275	0.06
Source w/o NI x Rate	6	831.868	138.645	0.14
Source w/ NI x Rate	4	1671.890	417.973	0.42
Source w/o NI vs. Source w/ NI x Rate	2	82.322	41.161	0.04
Check vs. Others	1	3584.422	3584.422	3.60
Error	63	62646.212	994.384	
Total	87	88090.791		

* Significant at the 0.05 probability level.
CV = 37.3%, SD = 32 kg N ha^{-1}.

Table 23. First harvest uptake of N in forage, 1986.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	kg N ha^{-1}				
With NI					
AN	.	83	88	104	92
UR	.	69	90	100	86
SCU	.	92	104	104	100
UAN	.	70	79	92	80
		Mean			
		79	90	100	86
With NI					
UR/DCD	.	100	122	114	112
UR/NS	.	70	79	92	80
UAN/NS	.	63	65	97	75
		Mean			
		78	89	101	89
All Sources	.	78	90	100	89
Check	56				

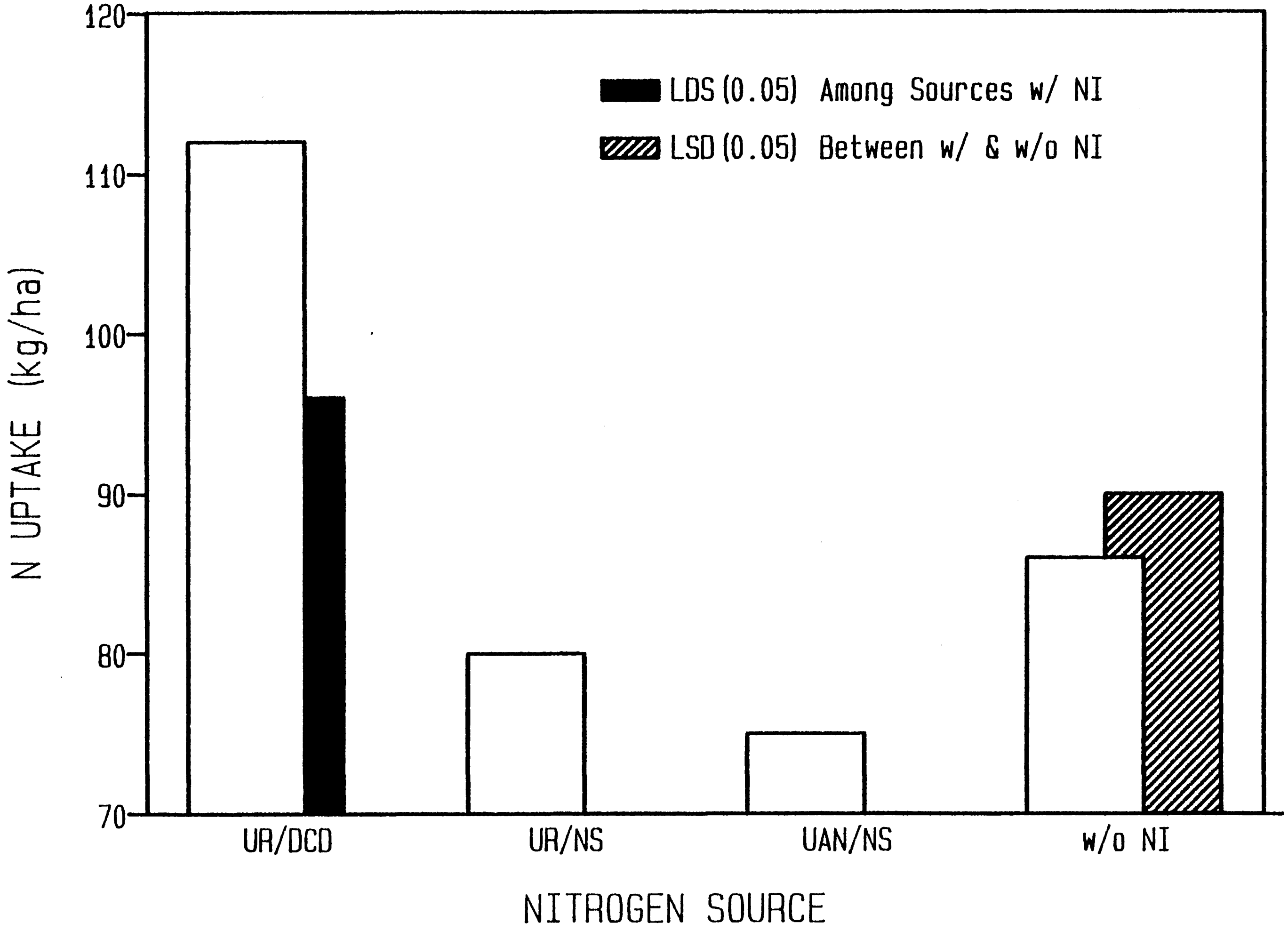

Fig. 4. First harvest uptake of N in forage as affected by N sources, 1986.

Second Harvest 1986

Dry Matter Yield

From the ANOVA (Table 24) N rates caused a significant main effect on yield and linear response at the 0.01 level of probability. Although the variation due to rate was highly significant (Table 24), the dry matter yield produced at the three rates applied over all sources was not significantly greater than that obtained from the check (Table 25) at the 5% level of detection ($LSD_{(0.05)} = 1.42$).

Tissue Nitrogen Concentration

Table 26 shows that rate of N had a highly significant quadratic effect on tissue N concentration. By inspection of Table 27, the increases in mean N concentration of the tissue were not of agronomic importance. Calculation of the LSD to detect any difference between the check and the mean N concentration for all sources at the 112, 224, and 448 kg N ha^{-1} rates confirm this ($LSD_{(0.05)} = 2.0$).

Nitrogen Uptake in Forage

Forage uptake of N showed significant differences among sources with NIs (Table 28). These differences are illustrated in Fig. 5, where Ur with DCD increased N yield in forage over other sources with NIs but not those sources without NIs. Rate also contributed to increases in N uptake as can be seen in Table 28. Because there were no significant differences among sources without NIs and the means for rate over these sources compare almost equally with those over all sources (Table 29), these mean values for rate give an indication of the magnitude of increase. A calculated LSD ($LSD_{(0.05)} = 15$) was used to determine differences between the rates of sources without NIs and the check. Only the 448 kg N ha^{-1} rate was different from the check.

Table 24. Analysis of variance for second harvest dry matter yield, 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	1.692	0.564	0.32
Treatment	21	43.466	2.070	1.18
Source w/o NI	3	1.767	0.589	0.34
Source w/ NI	2	10.120	5.060	2.88
Source w/o NI vs. Source w/ NI	1	0.007	0.007	0.00
Rate (All Sources)	2	18.018	9.009	5.13**
Linear	1	17.533	17.533	9.98**
Quadratic	1	0.406	0.406	0.23
Source w/o NI x Rate	6	6.093	1.016	0.58
Source w/ NI x Rate	4	3.784	0.946	0.54
Source w/o NI vs. Source w/ NI x Rate	2	3.440	1.720	0.98
Check vs. Others	1	2.595	2.595	1.48
Error	62	108.873	1.756	
Total	86	154.030		

** Significant at the 0.01 probability level.
CV = 36.3%, SD = 1.33 Mg ha^{-1}.

Table 25. Second harvest dry matter yield, 1986.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	Mg ha^{-1}				
Without NI					
AN	.	2.80	3.97	4.60	3.79
UR	.	2.74	3.79	4.35	3.62
SCU	.	3.28	4.87	3.71	3.95
UAN	.	3.19	3.55	3.56	3.43
			Mean		
		3.00	4.04	4.05	3.70
With NI					
UR/DCD	.	3.51	4.34	5.52	4.36
UR/NS	.	3.63	3.23	3.78	3.54
UAN/NS	.	2.49	2.90	4.06	3.15
			Mean		
		3.21	3.49	4.35	3.66
All Sources	.	3.09	3.81	4.17	3.68
Check	2.88				

Table 26. Analysis of variance for second harvest tissue N concentration, 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	3.768	1.256	0.35
Treatment	21	95.484	4.547	1.26
Source w/o NI	3	17.200	5.733	1.59
Source w/ NI	2	5.966	2.983	0.83
Source w/o NI vs. Source w/ NI	1	5.527	5.527	1.53
Rate (All Sources)	2	35.909	17.954	4.98**
Linear	1	6.617	6.617	1.84
Quadratic	1	29.292	29.292	8.13**
Source w/o NI x Rate	6	20.573	3.429	0.95
Source w/ NI x Rate	4	4.406	1.102	0.31
Source w/o NI vs. Source w/ NI x Rate	2	4.773	2.386	0.66
Check vs. Others	1	1.129	1.129	0.31
Error	63	226.990	3.603	
Total	87	326.242		

** Significant at the 0.01 probability level.
CV = 15.7%, SD = 1.9 g N kg^{-1}.

Table 27. Second harvest tissue N concentration, 1986.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	g N kg^{-1}				
Without NI					
AN	.	12.2	10.2	14.6	12.3
UR	.	11.5	11.3	13.0	11.9
SCU	.	13.8	12.3	13.8	13.3
UAN	.	12.3	11.2	11.8	11.8
		Mean			
		12.5	11.2	13.3	12.3
With NI					
UR/DCD	.	12.6	11.8	12.3	12.2
UR/NS	.	11.4	11.5	13.1	12.0
UAN/NS	.	11.5	10.8	11.4	11.3
		Mean			
		11.8	11.4	12.3	11.8
All Sources	.	12.2	11.3	12.9	12.1
Check	11.6				

Table 28. Analysis of variance for second harvest N uptake in forage, 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	639.425	213.142	1.12
Treatment	21	9344.053	444.955	2.34**
Source w/o NI	3	755.845	251.948	1.32
Source w/ NI	2	2425.220	1212.610	6.37**
Source w/o NI vs. Source w/ NI	1	1.591	1.591	0.01
Rate (All Sources)	2	4016.000	2008.000	10.55**
Linear	1	3822.253	3822.253	20.09**
Quadratic	1	218.854	218.854	1.15
Source w/o NI x Rate	6	1588.151	264.692	1.39
Source w/ NI x Rate	4	425.964	106.491	0.56
Source w/o NI vs. Source w/ NI x Rate	2	278.389	139.194	0.73
Check vs. Others	1	441.755	441.755	2.32
Error	62	11798.207	190.294	
Total	86	21781.685		

** Significant at the 0.01 probability level.
CV = 31.6%, SD = 14 kg N ha^{-1}.

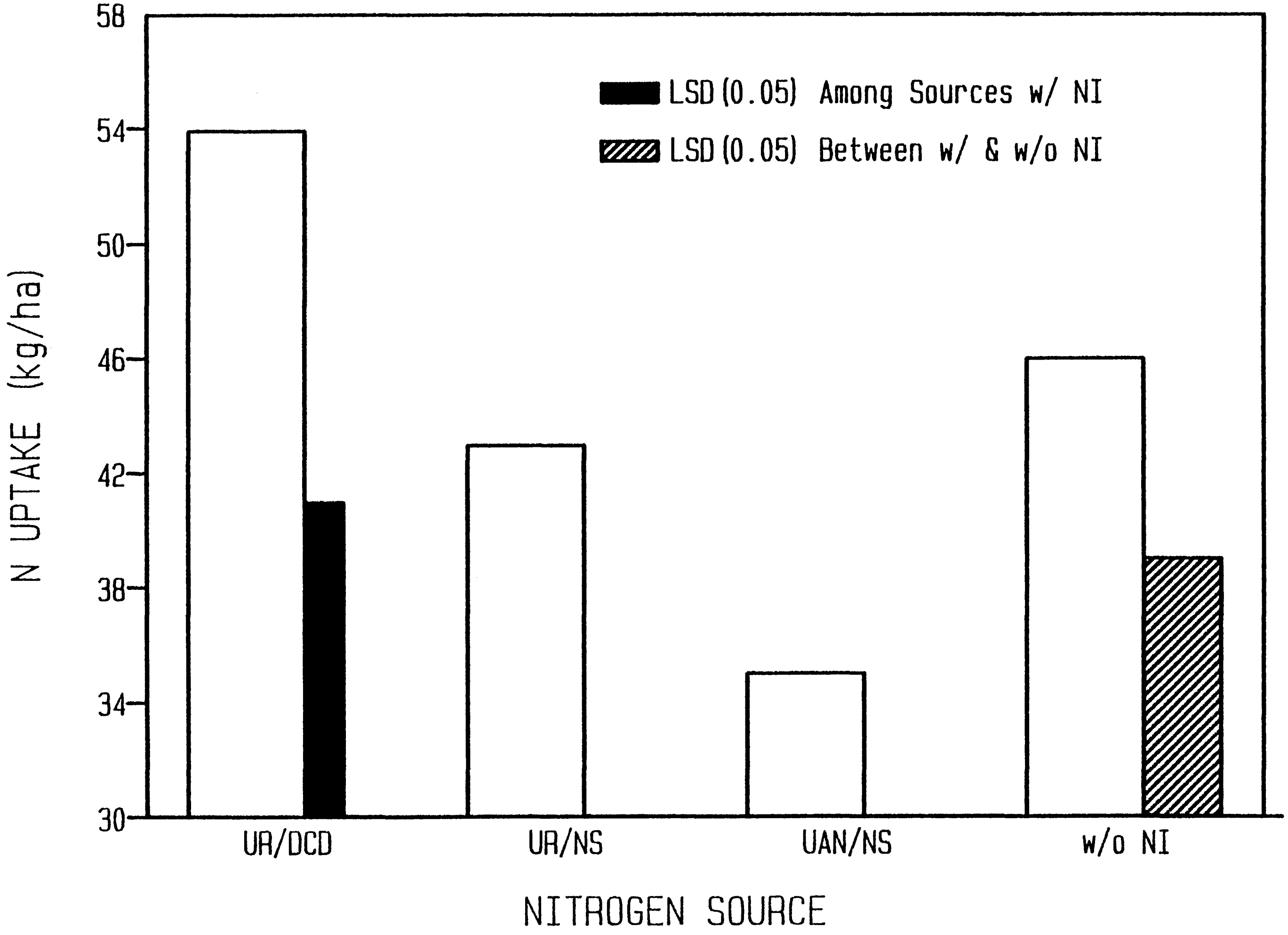

Fig. 5. Second harvest uptake of N in forage as affected by N sources, 1986.

Table 29. Second harvest uptake of N in forage, 1986.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	kg N ha^{-1}				
Without NI					
AN	.	34	40	67	47
UR	.	32	43	57	44
SCU	.	45	60	51	52
UAN	.	39	40	42	40
Mean		38	46	54	46
With NI					
UR/DCD	.	44	51	68	54
UR/NS	.	41	37	50	43
UAN/NS	.	29	31	46	35
Mean		38	40	55	44
All Sources	.	38	43	54	45
Check	33				

Harvest Totals For 1986

Dry Matter Yield

The total dry matter yield for 1986 reveals that there were significant differences among sources with NIs in 1986 (Table 30). An examination of the means from each of those sources in Table 31 shows that Ur with DCD produced greater yield than Ur and UAN with nitrapyrin. Figure 6 also shows that Ur with DCD increased yields over sources without NIs added. From Table 30 it can be seen that rates of N induced a linear response in dry matter yield.

Table 30. Analysis of variance for total dry matter yield summed over the first and second harvest, 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	7.156	2.385	0.28
Treatment	21	185.762	8.846	1.05
Source w/o NI	3	16.557	5.519	0.65
Source w/ NI	2	60.348	30.174	3.57*
Source w/o NI vs. Source w/ NI	1	2.971	2.971	0.35
Rate (All Sources)	2	43.594	21.797	2.58
Linear	1	40.307	40.307	4.77*
Quadratic	1	2.968	2.968	0.35
Source w/o NI x Rate	6	16.950	2.825	0.33
Source w/ NI x Rate	4	21.020	5.255	0.62
Source w/o NI vs. Source w/ NI x Rate	2	31.470	15.735	1.86
Check vs. Others	1	5.748	5.748	0.68
Error	62	524.081	8.453	
Total	86	716.999		

* Significant at the 0.05 probability level.
CV = 34.3%, SD = 2.91 Mg ha^{-1}.

Table 31. Total dry matter yield summed over the first and second harvest, 1986.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	Mg ha^{-1}				
Without NI					
AN	.	7.28	9.17	9.06	8.50
UR	.	6.66	8.95	9.10	8.24
SCU	.	8.17	11.36	8.41	9.31
UAN	.	7.33	8.11	7.61	7.68
			Mean		
		7.36	9.40	8.54	8.43
With NI					
UR/DCD	.	8.66	10.56	12.74	10.46
UR/NS	.	8.58	7.22	8.57	8.12
UAN/NS	.	6.56	6.70	9.64	7.63
			Mean		
		7.93	8.16	10.10	8.69
All Sources	.	7.61	8.86	9.18	8.54
Check	7.37				

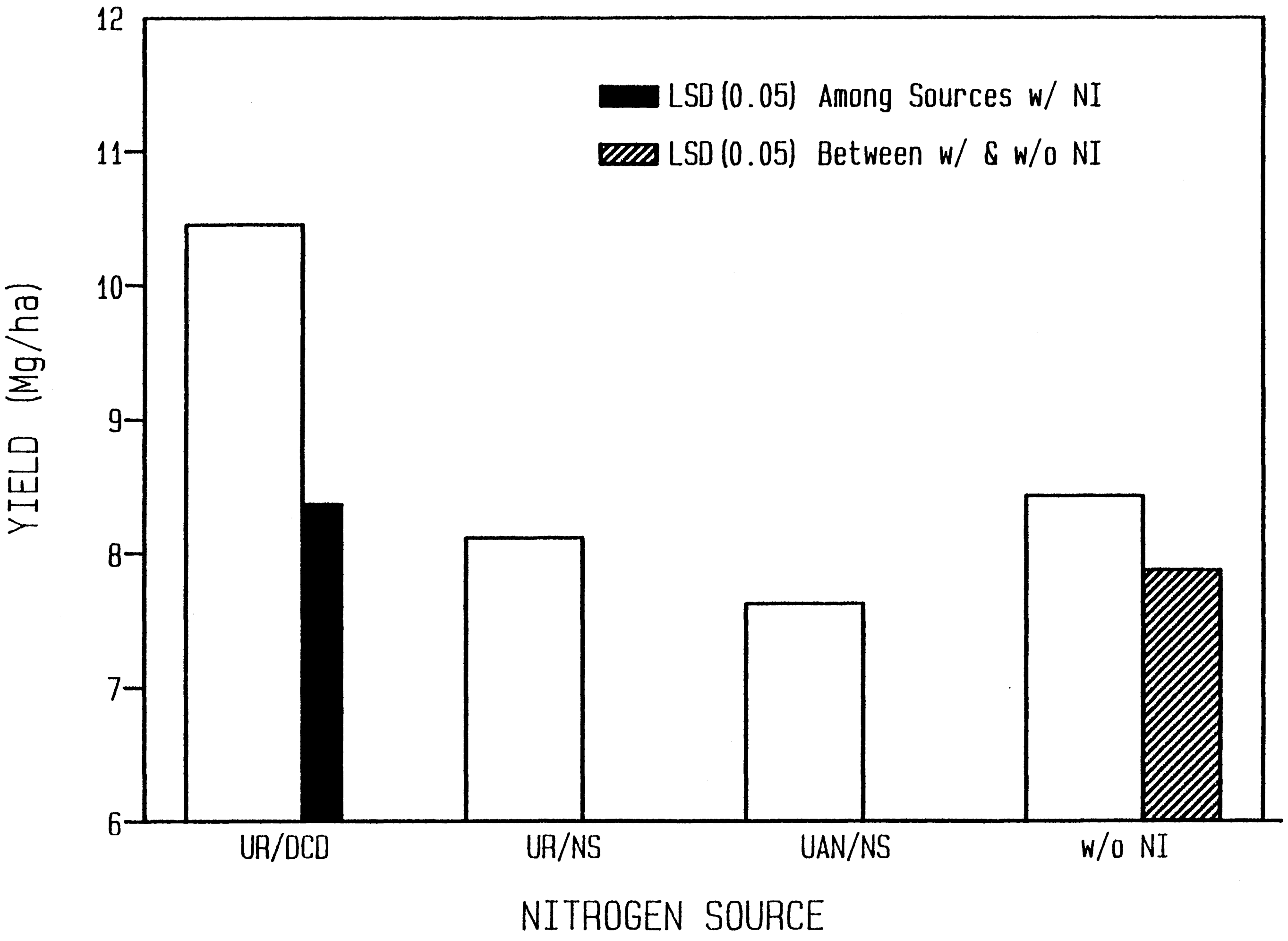

Fig. 6. Total dry matter yield summed over the first and second harvest as affected by N sources, 1986.

Nitrogen Uptake in Forage

Analysis of variance for total N uptake in forage (Table 32) shows that treatment significantly increased response over that obtained from the check plots. Sources with NIs showed significant differences among themselves (Table 32), Ur with DCD being greatest (Table 33). This response is illustrated in Fig. 7 where Ur with DCD is significantly greater than other sources with NIs or sources without NIs. Rates of applied fertilizer also influenced this increase in N uptake with a highly significant linear response (Table 32).

Table 32. Analysis of variance for total N uptake in forage summed over the first and second harvest, 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	3145.443	1048.481	0.67
Treatment	21	53416.470	2543.641	1.63
Source w/o NI	3	10018.142	3339.381	2.14
Source w/ NI	2	13918.144	6959.072	4.46*
Source w/o NI vs. Source w/ NI	1	15.148	15.148	0.01
Rate (All Sources)	2	16476.105	8238.053	5.28**
Linear	1	16475.032	16475.032	10.57**
Quadratic	1	8.146	8.146	0.01
Source w/o NI x Rate	6	4022.034	670.339	0.43
Source w/ NI x Rate	4	2219.572	554.893	0.36
Source w/o NI vs. Source w/ NI x Rate	2	404.890	202.445	0.13
Check vs. Others	1	6346.122	6346.122	4.07*
Error	62	96671.329	1559.215	
Total	86	153233.242		

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
CV = 31.0%, SD = 39 kg N ha^{-1}.

Table 33. Total N uptake in forage summed over the first and second harvest, 1986.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	kg N ha^{-1}				
Without NI					
AN	.	117	128	171	139
UR	.	101	133	157	130
SCU	.	137	164	155	151
UAN	.	109	119	134	121
Mean		116	136	154	135
With NI					
UR/DCD	.	144	173	182	166
UR/NS	.	111	114	142	122
UAN/NS	.	92	96	143	110
Mean		116	128	156	133
All Sources	.	116	132	155	134
Check	89				

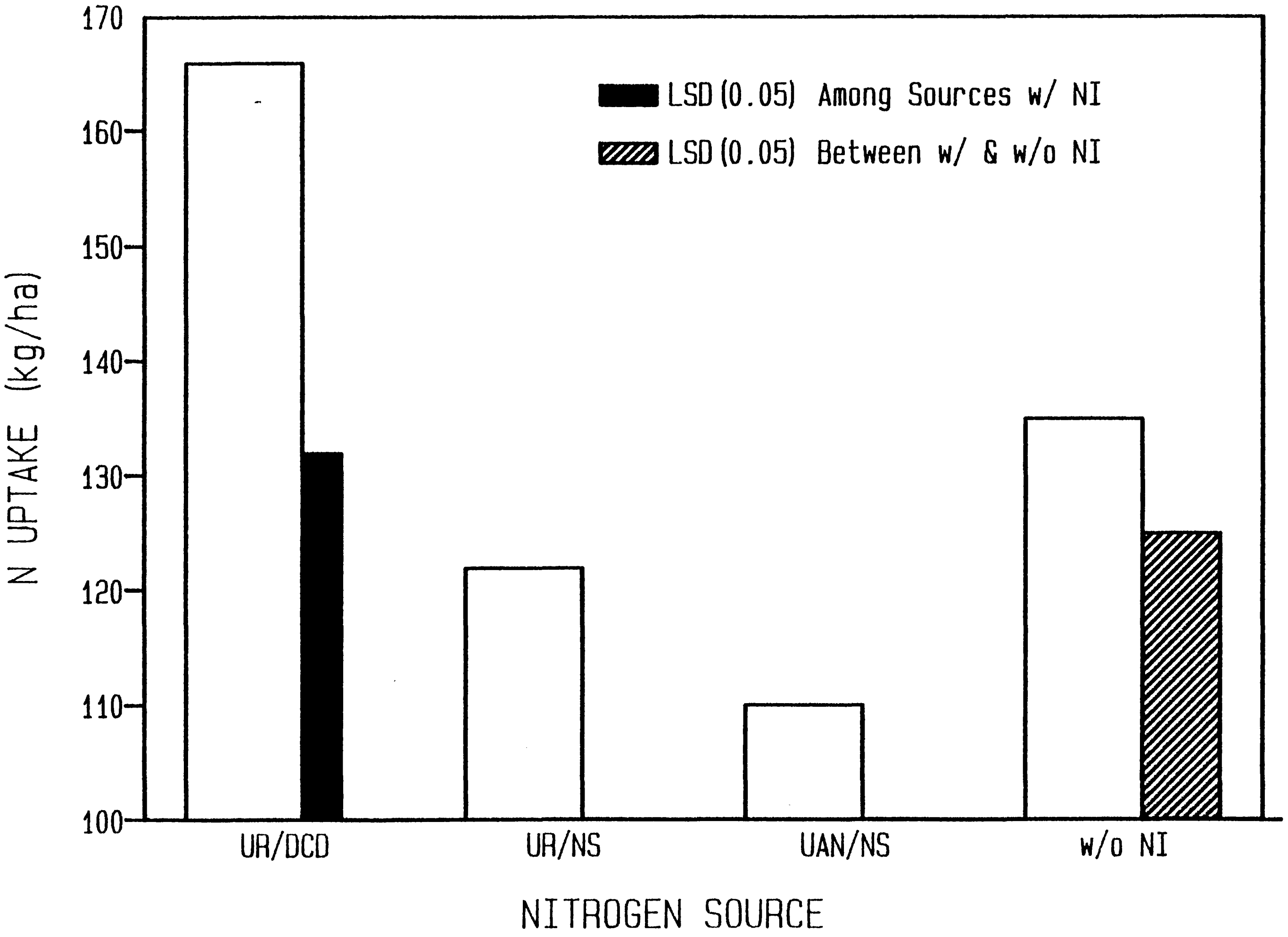

Fig. 7. Total N uptake in forage summed over the first and second harvest as affected by N sources, 1986.

Analysis of Pooled Data

Data for 1985 and 1986 were pooled for each harvest as well as totals, and a three-factor ANOVA, including factors of year, N source, and N rate, was conducted to determine if pooling would be permissable. The analysis where there was significance due to year, and therefore pooling of data not considered appropriate were: first harvest yield, first harvest N concentration, first harvest N uptake, second harvest yield, second harvest N uptake, and total N uptake. The two response variables that did not have a significant year term in the ANOVA were second harvest N concentration and total yield (Appendix Tables 1 and 2). Since there did not appear to be significant differences due to the two years, these two groups of pooled data were subjected to further ANOVA procedures to determine further characteristics.

Second Harvest N Concentration

A complete ANOVA was conducted on the pooled data as in the analysis for the individual years. The second harvest ANOVA for tissue N concentration shows that N rate caused a significant quadratic response (Table 34). To determine if this was of practical importance, an LSD was computed ($LSD_{(0.05)} = 1.8$) which showed that no tissue N concentration at any N rate for all sources was significantly different from the check (Table 35).

Table 34. Analysis of variance for the mean N concentration in tissue obtained from the second harvest of 1985 and 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	27.348	9.116	1.61
Treatment	21	125.455	5.974	1.06
Source w/o NI	3	14.027	4.676	0.83
Source w/ NI	2	11.478	5.739	1.02
Source w/o NI vs. Source w/ NI	1	9.482	9.482	1.68
Rate (All Sources)	2	48.052	24.026	4.26*
Linear	1	11.817	11.817	2.09
Quadratic	1	36.235	36.235	6.42*
Source w/o NI x Rate	6	12.415	2.069	0.37
Source w/ NI x Rate	4	14.474	3.619	0.64
Source w/o NI vs Source w/ NI x Rate	2	7.216	3.608	0.64
Check vs Others	1	8.311	8.311	1.47
Error	151	852.541	5.646	
Corrected Total	175	1005.344		

* Significant at the 0.05 probability level.
CV = 19.5%, SD = 2.4 g N kg^{-1}.

Table 35. Mean N concentration in tissue obtained from the second harvest of 1985 and 1986.

N Source	N Rate (kg N ha^{-1}) 0	112	224	448	Mean
	g N kg^{-1}				
Without NI					
AN	.	12.3	11.0	13.6	12.3
UR	.	12.2	10.9	12.4	11.9
SCU	.	13.2	12.3	13.0	12.8
UAN	.	12.4	11.9	13.9	12.7
Mean		12.5	11.5	13.2	12.4
With NI					
UR/DCD	.	12.0	11.7	12.1	11.9
UR/NS	.	11.7	11.9	13.7	12.4
UAN/NS	.	11.8	11.2	11.4	11.5
Mean		11.8	11.6	12.4	12.0
All Sources	.	12.2	11.6	12.9	12.2
Check	11.2				

Mean Annual Dry Matter Yield

The ANOVA for mean annual dry matter yield for 1985 and 1986 (Table 36) reveals that there were no significant differences due to the sources of N used. Rates of N applied did result in a highly significant linear response in dry matter yield (Table 36). The increases in yield over all sources in Table 37 were compared to the check ($LSD_{(0.05)}$ = 2.35), which showed no significant difference between yield produced at the 112, 224, or 448 kg N ha^{-1} rate and the yield produced from no applied N.

Table 36. Analysis of variance for mean annual dry matter yield obtained in 1985 and 1986.

Source	df	Sum of Squares	Mean Square	*F*
Block	3	9.84	3.281	0.33
Treatment	21	281.179	13.389	1.36
Source w/o NI	3	5.197	1.732	0.18
Source w/ NI	2	33.920	16.960	1.72
Source w/o NI vs Source w/ NI	1	7.677	7.677	0.78
Rate (All Sources)	2	147.125	73.562	7.47**
Linear	1	127.315	127.315	12.92**
Quadratic	1	19.214	19.214	1.95
Source w/o NI x Rate	6	37.503	6.250	0.63
Source w/ NI x Rate	4	14.155	3.539	0.36
Source w/o vs Source w/ NI x Rate	2	36.090	18.045	1.83
Check vs Others	1	4.568	4.568	0.46
Error	150	1477.815	9.852	
Corrected Total	174	1768.838		

** Significant at the 0.01 probability level.
CV = 36.7%, SD = 3.14 Mg ha^{-1}.

Table 37. Mean annual dry matter yield obtained in 1985 and 1986.

	N Rate (kg N ha^{-1})				
N Source	0	112	224	448	Mean
	Mg ha^{-1}				
Without NI					
AN	.	7.83	8.31	9.65	8.59
UR	.	6.55	9.48	9.55	8.53
SCU	.	6.68	10.01	8.97	8.55
UAN	.	5.86	10.04	8.18	8.02
		Mean			
		6.73	9.46	9.09	8.42
With NI					
UR/DCD	.	8.88	9.43	11.25	9.79
UR/NS	.	7.95	8.63	8.57	8.38
UAN/NS	.	7.35	7.73	9.96	8.35
		Mean			
		8.06	8.60	9.87	8.83
All Sources	.	7.30	9.09	9.41	8.60
Check	7.84				

CHAPTER V

SUMMARY AND CONCLUSIONS

Because of limited rainfall, growth of bermudagrass was limited and only two harvests were obtained in both years (Table 1). Another factor that limited the effectiveness of this fertility study was the high variability in the established bermudagrass sward and the response variables measured. This is supported by high coefficient of variation values in most cases, especially in dry matter yield. Generally response in the check plots was high relative to treatments which would be expected to produce significantly greater yields. This may be due to a large pool of organic N which goes undetected in a routine soil analysis. Blackmer (1986) conducted a study to determine the conditions where measurable yield responses should (and should not) be expected from treatments that conserve fertilizer N during production of corn in Iowa. He concludes that treatments conserving fertilizer N should be expected to cause statistically significant increases in corn yields only when a favorable interaction among the following conditions are attained: (i) experimental methods provide a high level of precision, (ii) the treatment saves a substantial portion of the fertilizer N applied, (iii) fertilizer N is applied at relatively low rates, and (iv) studies are conducted on soils having small amounts of soil-derived available N. Hergert and Wiese (1980) also reported that it is generally difficult to show any significant yield responses from applied

NIs, especially when the potential for N losses are small. They state that in experiments where a check and three N levels are used often the second N rate is in the range where maximum yields will be produced. This design probably will not show significant NI effects on yield unless large N loss occurs (Hergert and Wiese, 1980).

The results obtained in this study show that N rates will increase yield, N concentration, and N uptake in bermudagrass forage with few differences due to the N sources used. In both 1985 and 1986, the first harvest produced the largest crop, and second harvest response to the spring-applied N was nil. Urea with DCD did show some increases over other sources in 1986. This response is not thought to be due to its ability to increase available N under Oklahoma growing conditions where large losses of N do not generally occur due to leaching or denitrification and high soil temperatures prevail. Especially in light of reports cited in the literature.

The pooled data for total dry matter yield should supply powerful evidence for any differences due to N sources, rates, or NIs. Table 37 shows that nitrogen sources performed equally well in bermudagrass forage production, but N rates caused a linear increase in yield (Table 36).

LITERATURE CITED

Allen, S.E. 1984. Slow-release nitrogen fertilizers. p.195-205 *In* R.D. Hauck (ed.) Nitrogen in crop production. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Allen, S.E., and D.A. Mays. 1971. Sulfur-coated fertilizers for controlled release: agronomic evaluation. J. Agr. Food Chem. 19:809-812.

Allen, S.E., G.L. Terman, and H.G. Kennedy. 1978. Nutrient uptake by grass and leaching losses from soluble and S-coated urea and KCl. Agron. J. 70:264-268.

Amberger, A. 1981. Dicyandiamide as a nitrification inhibitor. p. 3-17. *In* Roland D. Hauck and Horst Behnke (eds.) Technical workshop in dicyandiamide, Muscle Shoals, AL. 4-5 December 1981. SKW Trostberg Ag., Trostberg, West Germany.

Anderson, W.B., and T.E. Kunkel, 1983. The effects of various nitrogen fertilizers on yield and N uptake of bermudagrass. p. 174-185. *In* Forage research in Texas. Texas Agric. Exp. Stn. CPR No. 4141.

Blackmer, A.M. 1986. Potential yield response of corn treatments that conserve fertilizer nitrogen in soils. Agron. J. 78:571-575.

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 workshop, Denver, CO. 5-7 March 1986. Potash & Phosphate Institute and Foundation for Agronomic Research. Atlanta, GA.

Boswell, F.C., L.R. Nelson, and M.J. Bitzer. 1976. Nitrification inhibitor with fall-applied vs. Split nitrogen applications for winter wheat. Agron. J. 68:737-740.

Bundy, L.G., and J.M. Bremner. 1973. Inhibition of nitrogen in soils. Soil Sci. Soc. Am. Proc. 73:396-398.

D.L. Nofziger, J.R. Williams, H.J. Barreto, and D.B. Reynolds. 1986. Turbostat: a data management, statistics, and graphics system. Computer Software Series CSS-22 Agricultural and Experiment Station Division of Agric. Oklahoma State Univ. Stillwater, OK.

Frye, W.W., R.L. Blevins, L.W. Murdock, K.L. Wells, and J.H. Ellis. 1981. Effectiveness of nitrapyrin with surface-applied fertilizer nitrogen in no-tillage corn. Agron. J. 73:287-289.

Gautney, J., Y.K. Kim, and P.M. Gagen. 1983. Feasibility of incorporating the nitrogen loss inhibitors dicyandiamide, thiourea, phenyl phosphorodiamidate, and potassium ethyl xanthate into granular urea. NFDC Bull. Y-182 TVA/OACD - 83/16.

Hageman, R.H. 1980. Effect of form of nitrogen on plant growth. p.47-62. *In* J.J. Meisinger et al. (ed.) Nitrification inhibitors-potentials and limitations. Spec. Pub. 38. American Society of Agronomy, Madison. WI.

Hanlon, E., and G. Johnson. 1983. OSU agronomic services´ procedure for soil, forage, and water testing. OSU fact sheet 2901. Cooperative Extension Service, Division of Agric., Oklahoma State Univ., Stillwater, OK.

Hauck, R.D. 1984. Technological approaches to improving the efficiency of nitrogen fertilizer use by crop plants. p.551-560 *In* R.D. Hauck (ed.) Nitrogen in crop production.American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Hergert, G.W., and R.A. Wiese, 1980. Performance of nitrification inhibitors in the Midwest (west). p. 89-105. *In* J.J. Meisinger et al.(ed.) Nitrification inhibitors-potentials and limitations. Spec. Pub.38. American Society of Agronomy, Madison. WI.

Hill, W.E., and B.B. Tucker. 1968. A comparison of injected anhydrous ammonia into bermudagrass sod compared to top-dressed applications of urea and ammonium nitrate. Soil Sci. Soc. Am. Proc. 32:257-261.

Hoeft, R.G. 1984. Current status of nitrification inhibitor use in U.S. agriculture. p.561-569 *In* R.D. Hauck (ed.) Nitrogen in crop production.American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Hummel, Jr., N.W., and D.V. Waddington. 1981. Evaluation of slow-release nitrogen sources on Baron Kentucky Bluegrass. Soil Sci. Soc. Am. J. 45:966-970.

Johnson, G., and L. Rommann. 1983. Available nitrogen: bermudagrass and other forages. OSU fact sheet 2225. Cooperative Extension Service, Division of Agric., Oklahoma State Univ., Stillwater, OK.

Mosdell, D.K., W.H. Daniel, and R.P. Freeborg. 1986. Evaluation of dicyandiamide-amended fertilizers on Kentucky bluegrass. Agron. J. 78:801-806.

Onken, A.B. 1980. Performance of nitrification inhibitors in the Southwest. p. 119-129. *In* J.J. Meisinger et al. (ed.) Nitrification inhibitors-potentials and limitations. Spec. Pub. 38. American Society of Agronomy, Madison. WI.

Randall, G.W., and G.L. Malzer. 1981. Corn production in south central Minnesota as influenced by dicyandiamide (DCD). p. 38-46. *In* Roland D. Hauck and Horst Behnke (eds.) Technical workshop in dicyandiamide, Muscle Shoals, AL. 4-5 December 1981. SKW Trostberg Ag., Trostberg, West Germany.

Reddy, G.R. 1964. Effect of mixing varying quantities of dicyandiamide with ammonium fertilizers on nitrification of ammonia in soils. Can. J. Soil Sci. 44:254-259.

Russel, D.A. 1984. Conventional nitrogen fertilizers. p.183-194 *In* R.D. Hauck (ed.) Nitrogen in crop production.American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Statistical Analysis System Staff. 1985. SAS procedures guide for personal computers version 6 edition. SAS Institute Inc., Cary, NC.

Touchton, J.T. 1981. Effect of Didin on nitrification of urea-N, wheat growth, and grain yield. p. 53-61. *In* Roland D. Hauck and Horst Behnke (eds.) Technical workshop in dicyandiamide, Muscle Shoals, AL. 4-5 December 1981. SKW Trostberg Ag., Trostberg, West Germany.

Touchton, J.T., R.G. Hoeft, and L.F. Welch. 1979. Effect of nitrapyrin on nitrification of broadcast- applied urea, plant nutrient concentrations, and corn yield. Agron. J. 71:787-791.

Westerman, R.L., M.G. Edlund, and D.L. Minter. 1981. Nitrapyrin and etradiazole effects on nitrification and grain sorghum production. Agron. J. 73:697-702.

Westerman, R.L., R.J. O'Hanlon, G.L. Fox, and D.L. Minter. 1983. Nitrogen fertilizer efficiency in bermudagrass production. Soil Sci. Soc. Am. J. 47:810-817.

Varsa, E.C., S.L. Liu, and G. Kapusta. 1984. Use of nitrification inhibitors with urea and urea-ammonium nitrate (UAN) solution in wheat production. J. Fert. Issues 1:118-124.

Vilsmeier, K. 1981. Action and degradation of dicyandiamide. p. 18-24. *In* Roland D. Hauck and Horst Behnke (eds.) Technical workshop in dicyandiamide, Muscle Shoals, AL. 4-5 December 1981. SKW Trostberg Ag., Trostberg, West Germany.

Table 1. Analysis of variance for N concentration in tissue obtained from the second harvest of 1985 and 1986, to determine if pooling of data was appropriate.

Source	df	Sum of Squares	Mean Square	*F*
Blocks	3	25.269	8.423	1.35
Year	1	1.907	1.907	0.31
N Source	6	34.991	5.832	0.93
N Rate	2	48.058	24.029	3.85*
Year x N Source	6	33.018	5.503	0.88
Year x N Rate	2	2.703	1.352	0.22
N Source x N Rate	12	34.160	2.847	0.46
Year x N Source x N Rate	12	42.393	3.533	0.57
Error	123	767.446	6.239	
Total	167	989.946		

* Significant at the 0.05 probability level.
CV = 20.4%, SD = 2.5 g N kg^{-1}.

Table 2. Analysis of variance for mean annual dry matter yield in 1985 and 1986, to determine if pooling of data was appropriate.

Source	df	Sum of Squares	Mean Square	*F*
Blocks	3	16.754	5.585	0.55
Year	1	0.157	0.157	0.02
N Source	6	49.062	8.177	0.81
N Rate	2	149.164	74.582	7.35**
Year x N Source	6	44.502	7.417	0.73
Year x N Rate	2	9.574	4.787	0.47
N Source x N Rate	12	88.932	7.411	0.73
Year x N Source x N Rate	12	100.750	8.396	0.83
Error	123	1238.680	10.218	1.01
Total	167	1688.276		

* Significant at the 0.05 probability level.
CV = 20.4%, SD = 3.19 Mg ha^{-1}.

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