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ABSTRACT

SPACINGS AND RATES OF ANHYDROUS AMMONIA ON FIVE GRASSES COMPARED TO AMMONIUM NITRATE FOR YIELD AND NITRATE-N CONTENT OF THE HERBAGE AND THE SOIL

By

John Bertel Schou

Objectives of this study were to compare the effects of anhydrous ammonia to ammonium nitrate, a standard nitrogen source, on yields of herbage and on the accumulation of nitrate-N in the foliage and in the soil. Eight-month old stands of deep-rooted smooth brome grass (Bromus inermis Leyss.), reed canarygrass (Phalaris arundinacea L.), tall fescue (Festuca arundinacea Schreb.), and orchardgrass (Dactylis glomerata L.) and shallow-rooted Kentucky bluegrass (Poa pratensis L.) were fertilized on a Conover loam soil in the spring of the first year with anhydrous ammonia injected 13-cm deep at rates of 112, 224, 448, and 896 kg N per hectare in 25-, 51-, 76-, and 102-cm rows, and with similar rates of N as ammonium nitrate broadcast in split applications.

Total effects of the N treatments were evaluated by combining the yields of three cuts in the first year and three cuts in the second year. Nitrate-N in the foliage

was determined in the first and second cuttings in both years. Nitrate-N in the soil was determined below a shallow- and a deep-rooted grass at increments of 15 cm to a depth of 152 cm in July and November of both years. Nitrate-N was determined by the specific ion electrode method.

Yields of grasses were lower initially with anhydrous ammonia than with ammonium nitrate but yields in the third cutting of the first year and in all cuttings in the second year favored anhydrous ammonia. Row spacing had no effect on total yield of the deep-rooted grasses but Kentucky bluegrass yielded less at the two widest row spacings at all but the lowest rate of nitrogen. At the end of the first year there was a 100% stimulation of all grasses between 25- and 51-cm rows of anhydrous ammonia or with 896 kg N per hectare at all spacings. By the end of the second year, all grasses were stimulated 100% by 896 kg N per hectare as anhydrous ammonia spaced 102 cm apart. Grasses yielded in the order bromegrass > tall fescue > reed canarygrass > orchardgrass > bluegrass. Yields of the four deep-rooted grasses were 5, 12, 5, and 2 percent greater at rates of 112, 224, 448, and 896 kg N per hectare as anhydrous ammonia, respectively, than with ammonium nitrate.

Grasses increased in nitrate-N in the foliage with increased N. Orchardgrass had the highest levels of nitrate-N whereas tall fescue, reed canarygrass, and bromegrass had intermediate levels. Bluegrass had the lowest levels.

Grasses fertilized with 112 kg N from both N sources were always below 0.15 percent nitrate-N (accepted "safe" for livestock). Second-year levels of nitrate-N were considered safe.

Accumulation of nitrate-N in the soil was greater from anhydrous ammonia than from ammonium nitrate and, after three months, nitrate-N had leached to a depth of 30 to 45 cm. Deep-rooted bromegrass removed more total nitrate-N than shallow-rooted bluegrass. Nitrate-N from fertilizer N remained in the upper 76 cm of the soil profile in the first year with the exception of the 896-kg rate of N on bluegrass. At the 224-kg rate of N, higher grass yields with anhydrous ammonia than with ammonium nitrate in the first year were related to soil nitrate-N levels. With 448- and 896-kg rates of N, nitrate-N in the soil was leached to greater depths the first year. Eighteen months after N application, nitrate-N was still accumulating in the surface 76 cm from anhydrous ammonia but not from ammonium nitrate. Nitrate-N from the higher rates of N with both sources was at or exceeded the depth of 122 cm, determined as the maximum root depth of bromegrass. This nitrate-N could contribute to ground water contamination.

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Crop and Soil Science

1973

ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Dr. M. B. Tesar for his assistance and encouragement in the research and for his constructive criticism in the preparation of this manuscript.

Appreciation is also expressed to Drs. B. G. Ellis, J. B. Beard, R. E. Monroe, and P. G. Murphy for serving as guidance committee members.

My days at Michigan State University (September 1970 to March 1973) went fast, but the many friendships and acquaintances made while there will not be forgotten.

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INTRODUCTION

Our economically-conscious and ecologically-oriented society strives for increased efficiency in agricultural production while protecting the environment. Economical grass production depends on an economical source of nitrogen. Ideally, the source of N should not contaminate ground water with nitrate. Nitrate stimulates the growth of algae in lakes, rivers, and streams. If nitrate contaminates well water, it may pose a hazard to human health (Smith, 1970).

Per unit of N, anhydrous ammonia is the most economical source of N. In 1970, the price of N as anhydrous ammonia was about one-half the cost of N as ammonium nitrate. Furthermore, the N from anhydrous ammonia is not readily leached from the zone of injection because it is in the positively-charged ammonium form which is bound by negatively-charged soil particles. Nitrification of ammonium to nitrate-N proceeds only when the pH decreases to a tolerable level for nitrifying bacteria to live.

There is a lack of information on yields of cool-season grasses fertilized with anhydrous ammonia in the United States. The lack of proper application equipment

and the technology of application has hindered widespread use of anhydrous ammonia on grassland.

Nitrate concentration in grass foliage is important because ruminant animals reduce the nitrate from the grass to the highly toxic nitrite compound. Again, little information is available on the effect of anhydrous ammonia on the nitrate content of the grass.

The removal of soil nitrate by grass would prevent nitrate pollution of ground water. No data are available in the literature indicating the movement of soil nitrate from anhydrous ammonia to depths below grass roots.

This investigation is divided into three sections as follows:

- I. Production of grass
- II. Nitrate accumulation in the foliage
- III. Nitrate accumulation in the soil.

SECTION I

PRODUCTION

A. Literature Review

Large acreages of Northeastern and Northcentral United States grass pastures show a marked need for nitrogen (N). Today probably less than 5% of 50 million acres of this grassland is fertilized, partly because of the high cost per unit of N. Ammonium nitrate (AN) at \$0.20/kg of N (USDA, 1970) gives only a marginal return in forage yield. Fertilization of temperate region grasses has increased dry matter forage yields at least 2.2 mt/ha with 112 kg N/ha (Lucey, 1959, Kennedy, 1960, Ramage, et al., 1958, Wagner, 1954, Washko and Marriott, 1960, Mitchell, 1967, and Tesar, Hansen, and Robertson, 1972).

A more economical N source than AN per unit of N is anhydrous ammonia (AA) which costs \$0.10/kg of N (USDA, 1970). However, application costs for AA are greater than AN, and the technology for application of AA is meager.

Most of the limited work showing the effects of AA on grass has been done in the southern states on warm-season southern grasses. The first reported work was

conducted in Mississippi by Andrews, Neely, and Edwards (1951) and Andrews (1956). Andrews, et al. (1951) reported higher yields of warm-season grasses in Mississippi with AA than with AN, and they stressed the value of AA as an economical source of N. Andrews (1956) reviewed studies where oats (Avena sativa L.), and a tall fescue (Festuca arundinacea Schreb.) and hop clover (Trifolium dubium L.) stand produced greater forage yields with AA than with AN. Nitrogen in 46-cm spacings gave greater total yields than at 69- or 91-cm spacings, but yields in the third cutting were the same for all spacings at 112 kg N/ha. The higher total yield of the fescue-clover stand with AA than AN was attributed to nitrification and later leaching of AN from the topsoil while a pH 4.9 retarded nitrification of AA in the root zone. Dallis grass (Paspalum dilatatum Poir.) in Mississippi in a dry year also produced higher forage yields with 111 kg N/ha of AA in 41-cm spacings than with AA in 82-cm spacings or with AN broadcast (Andrews, 1956).

Bermudagrass (Cynodon dactylon L.), another warm-season grass, has been effectively fertilized with AA in the southern United States. Burton and Jackson (1962) in Georgia reported AA applied in 41-cm rows was 94% as effective as AN in increasing forage yields. Grass fertilized with AA consistently produced highest yields in the second and third cuts when compared with AN or ammonium sulfate. Hill and Tucker (1968) in Oklahoma confirmed the higher

yields with AN on bermudagrass in early cuttings and the higher yields in later cuttings with AA. With 40-cm injection spacings on a silt loam soil, grass yields were similar at rates of 112, 165, and 220 kg N/ha of AA in the first cut, apparently because the lowest rate supplied adequate N. They attributed the lack of total yield increase from the high rate of AA at 30- and 40-cm spacings to sod burn and poor retention of NH_3 .

European research with AA on grass has been primarily on ryegrass (Lolium perenne L.), a short-rooted, drought-susceptible, cool-season grass. Burg, Brakel, and Schepers (1967a) in the Netherlands reported ammonium nitrate limestone (23% N) gave higher yields than AA in a dry year. Optimum dry matter forage yield was at 25 cm. At 40-cm spacings, a 10-cm N deficient area was evident between injections. Diffusion of NH_3 was 10 cm on either side of the injections. Burg, Brakel, and Schepers (1967b) observed that root injury from AA injection accounted for yield decreases. Jeater (1967) in England reported that under sandy conditions, split AA treatments yielded more than single applications, but both AA treatments were inferior to AN. No indication of the amounts of NH_3 loss or root injury was reported. Cowling (1968) found that individual AA injections 10-cm deep on 1-m square plots produced less forage than AN under dry conditions. The grass yields from AA were good in the first

cutting, but did not provide a continuing supply of N. Split applications of AN totaling 400 kg N/ha gave much greater yields than a single application on a sandy clay loam. Drysdale (1970), however, reported a greater yield of timothy (Phleum pratense L.) with AA than with an equivalent N rate with AN. When AN was applied in split applications, timothy fertilized with AN yielded more.

Tesar, Hansen, and Robertson (1971, 1972) in Michigan compared AA applicator knives on a mixture of cool-season pasture stands. They noted greater losses of NH_3 with a rolling coulter-knife applicator than with a vertical knife. First-year yields favored AN. Total yields of first- and second-year yields from fertilization in the first year were similar with AN and AA. Yields from spacings of AA at 25, 51 and 76 cm were equal.

The objective of this study was to determine the responses and yields of four deep-rooted grasses and one shallow-rooted grass when fertilized with broadcast AN at four rates of N and at similar rates of AA applied in four row spacings.

B. Materials and Methods

A Conover loam soil on the Michigan State University research farm at East Lansing, Michigan, was used for this two-year study. The area was limed to pH 6.5 and 227 kg/ha of 0-20-20 was disked into the soil. The

perennials 'Lincoln' smooth brome grass (SB) (Bromus inermis Leyss.), 'commercial' reed canarygrass (RC) (Phalaris arundinacea L.), 'Penmead' orchardgrass (OG) (Dactylis glomerata L.), 'Kentucky 31' tall fescue (TF) (Festuca arundinacea Schreb.), and 'common' Kentucky bluegrass (KB) (Poa pratensis L.) were sown August 14, 1970, at 11, 45, 34, 34, and 45 kg/ha, respectively. Excellent stands of grasses were established. Broadleaf weeds were controlled with 1/2 kg/ha 2,4-D amine applied October 8, 1970.

A split-plot design with the large block being grass species was used in four replications. A plot size of 1.9 x 9.1 m for each fertilizer treatment was used. This permitted a minimum border of 36 cm between the closest treatments. Anhydrous ammonia was injected to a depth of 13 cm April 29, 1971, with an applicator attached to a tractor (Figure 1). The vertical knives attached to the experimental applicator are shown in Figure 2. Design of the anhydrous ammonia sod knife was described by Hansen, Tesar, and Robertson (1970). The soil temperature was 10 C and the soil moisture content was 12%. Desired application rates were determined by calibration and trial runs. Rates of N were varied by regulating tractor speed. There was a minimum loss of NH_3 . Treatments of 112, 224, 448, and 896 kg N/ha were applied with injection knives spaced 25, 51, 76, and 102 cm for each rate, making a total of 16 treatments of AA. The following number of rows of NH_3 were



Figure 1. Anhydrous ammonia applicator with three vertical knives.

attained for the four spacings of AA by making one or two trips with the applicator equipped with two or three knives: 25 cm - 6 rows; 51 cm - 4 rows ; 76 cm - 3 rows; and 102 cm - 2 rows. Similar rates of N as AN were applied broadcast in one application or split as follows:

112 kg N/ha - all on May 7

224 kg N/ha - all on May 7

448 kg N/ha - 224 on May 7; 112 on May 26; 112 on June 16

896 kg N/ha - 224 on May 7; 112 on May 26; 112 on June 16;
224 on July 9; 224 on July 14.

The AN was applied in split applications at the two higher rates to minimize possible fertilizer injury. The AN was



Figure 2. Vertical knife designed for anhydrous ammonia application to grass. The horizontal curved plate, designed by C. M. Hansen, Department of Agricultural Engineering, was welded to the commercial vertical knife to keep NH_3 loss to a minimum.

applied with a 1.67-m fertilizer spreader calibrated to deliver desired rates by accurate regulation of the speed of the tractor used to tow the spreader. In calibration runs, the AN was collected in an attached tray.

The average monthly precipitation, air and soil temperature, and irrigation for the growing season in 1971 and 1972 are shown in Table 1. The grasses were irrigated

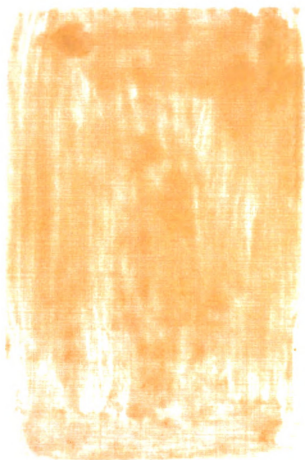


Table 1. Average monthly precipitation, air and soil temperature, and irrigation during the first (1971) and second (1972) growing season at East Lansing, Michigan.

Month	Temperature, C ⁺				Precipitation, cm ⁺⁺		Avg. 1961- 1972
	Air		Soil		1971	1972	
	1971	1972	1971	1972			
April	7.8	6.6	4.7	4.4	3.25	8.53	7.01
May	13.5	15.5	12.3	14.8	4.24	7.47	6.43
June	21.7	18.4	20.6	19.6	10.04	6.05	11.68
Irrigation, 6/20					5.08		
July	20.5	21.7	22.2	23.0	8.18	6.27	7.75
Irrigation, 7/25						5.08	
August	20.7	20.6	21.6	21.7	4.24	8.89	6.78
Irrigation, 8/25					3.81		
September	19.1	17.4	19.8	18.8	7.72	10.67	7.47
October	15.2	8.6	15.6	12.1	2.74	7.87	4.47
Total					49.30	60.83	51.59

⁺Recorded by environmental data service, U.S. Department of Commerce, East Lansing, Michigan, air temperature at 5 p.m. and soil temperature 10-cm deep at 5 p.m. in a Miami fine sandy loam under fescue grass.

⁺⁺Recorded at the crops research field laboratory, Michigan State University, East Lansing, Michigan and included irrigation.

with 5 cm on June 20 and 3.8 cm on August 25, 1971, during droughty periods, and with 5-cm water on July 25, 1972.

Cuttings of grass were made on June 11, July 28, and October 20, 1971, and on May 26, July 10, and October 19, 1972. A diagonal strip 0.9 x 8.2 m was harvested to a 5-cm height from each plot to get representative fertilization of the AA applied in the four-row spacings. The center of the strip was 0.3 m to the left of the center at the beginning of the 8.2-m length and 0.3 m to the right of the center at the far end of the plot. A self-propelled harvester was used. Borders were cut with a rotary mower and removed. Dry matter was determined from 1000-g samples of chopped forage dried with forced air for 24 hours at 54 C. Yields are expressed in metric tons per hectare (mt/ha) of forage containing 12% moisture.

C. Results and Discussion

First Year (1971)

Smooth brome grass was the highest yielding grass followed in order by reed canarygrass, tall fescue, orchardgrass, and Kentucky bluegrass (Table 2). At the two lowest rates of AN or AA, yields of bluegrass were significantly lower than the four deep-rooted grasses. At the two highest rates of N, the yield differences between bluegrass and the four deep-rooted grasses were much smaller.

Table 2. First-year forage yield in 1971 in mt/ha of five grasses fertilized on April 29, 1971, with AA and with AN in split applications on May 7 and 26, June 16, July 9 and 14, 1971.

Spacing, cm	N rate, kg/ha	Grass species					Avg SB, RC, OG, TF	Avg All
		SB	RC	OG	TF	KB		
	0	8.67	3.87	4.19	5.49	1.77	5.56	4.84
		AMMONIUM NITRATE						
	112	10.52	7.46	6.83	7.59	4.94	8.10	7.47
	224	12.68	10.17	8.62	9.79	7.77	10.32	9.81
	448	13.47	10.84	10.20	11.03	8.78	11.39	10.86
	896	14.01	11.44	9.83	10.53	9.20	11.45	11.00
	Avg	12.67	9.98	8.87	9.74	7.67	10.32	9.79
LSD .05							--	--
		Two grasses within a N rate = 0.91 ⁺					0.35	0.31
		N rates within a grass(es) = 0.69 ⁺						
		ANHYDROUS AMMONIA						
25	112	12.14	8.35	8.00	7.87	5.61	9.09	8.39
	224	13.68	9.89	9.68	10.75	7.86	11.00	10.37
	448	13.03	9.87	8.91	10.13	8.55	10.49	10.10
	896	10.18	8.58	8.77	9.24	7.33	9.19	8.82
	Avg	12.26	9.19	8.84	9.49	7.34	9.94	9.42
51	112	12.47	8.69	7.71	8.91	5.17	9.45	8.59
	224	13.79	10.27	9.80	9.96	8.40	10.96	10.44
	448	12.95	10.30	9.61	9.72	8.81	10.65	10.28

896	11.23	9.62	10.11	9.21	8.57	10.04	9.75
Avg	12.61	9.72	9.31	9.45	7.74	10.27	9.77
76	112	12.00	8.34	8.80	8.14	4.90	8.44
224	11.95	8.85	8.78	9.56	6.06	9.79	9.04
448	13.16	9.77	9.58	9.82	7.06	10.58	9.88
896	12.85	9.71	9.90	9.85	8.27	10.58	10.12
Avg	12.49	9.17	9.27	9.34	6.57	10.07	9.37
102	112	10.90	7.96	6.96	8.44	4.87	7.83
224	12.34	8.17	8.76	9.33	6.00	9.65	8.92
448	12.81	8.37	9.53	9.12	5.76	9.96	9.12
896	11.52	9.12	10.10	9.33	7.40	10.02	9.49
Avg	11.89	8.41	8.84	9.06	6.01	9.55	8.84
LSD .05	Two grasses within a spacing and a N rate = 1.30 ⁺						
	Spacings within a grass(es) and a N rate = 1.19 ⁺						
	N rates within a spacing and a grass(es) = 0.96 ⁺						
All	112	11.88	8.34	7.87	8.34	5.14	8.31
224	12.94	9.30	9.36	9.90	7.08	10.35	9.69
448	12.99	9.58	9.41	9.70	7.55	10.42	9.85
896	11.44	9.26	9.72	9.41	7.89	9.96	9.55
Avg	12.31	9.12	9.07	9.34	6.92	9.96	9.35

⁺Value for comparing any two grasses.

The grasses did not react similarly in their yield response to the four rates of N applied as AA or AN. Grass yields increased as N as AA increased to 224 kg/ha but increased up to 448 kg N as AN. Yields of bromegrass, reed canarygrass, and bluegrass increased as N rates as AN increased from 448 to 896 kg/ha, while yields of orchardgrass and tall fescue decreased. Average yields of the deep-rooted grasses shown in Table 2 were higher in all cases than the shallow-rooted bluegrass.

All grasses produced more forage in 1971 when fertilized with AA than with AN at 112 kg N/ha (Table 2). The average yield for all grasses with 112 kg N as AA was 8.31 mt/ha compared to 7.47 mt/ha for AN. This was a 11% advantage for AA.

All of the five grasses fertilized with AA consistently produced lower yields in the first cutting than when fertilized with AN (Figure 3), but in the second and third cuttings the highest yields were usually obtained when AA was applied. This agrees with work on southern grasses by Andrews (1956), Burton and Jackson (1962), and Hill and Tucker (1968). At higher rates of AA, foliage injury was observed (Figure 4 and Table 3). The burned area is clearly shown in Figure 5 on several grasses two weeks after being fertilized with 896 kg N as AA in 76-cm rows. Figure 6 shows how well orchardgrass at the high rate of N (shown in the foreground of Figure 5) had recovered from the burn

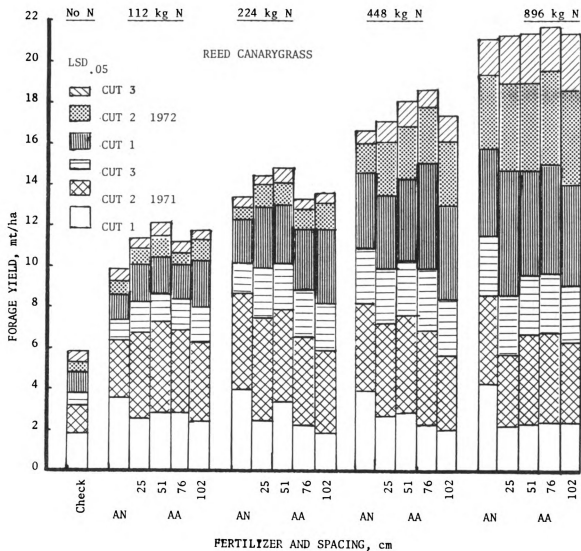


Figure 3. Two-year total of forage yield in mt/ha of five grasses in 1971 and 1972 by individual cuts. Grasses were fertilized on April 29, 1971, with AA in four row spacings and with AN in split applications on May 7 and 26, June 16, July 9 and 14, 1971.

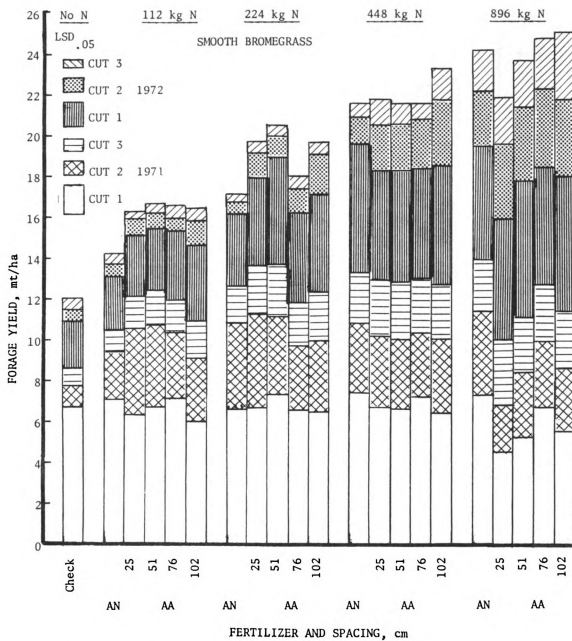


Figure 3 (cont'd)

2000

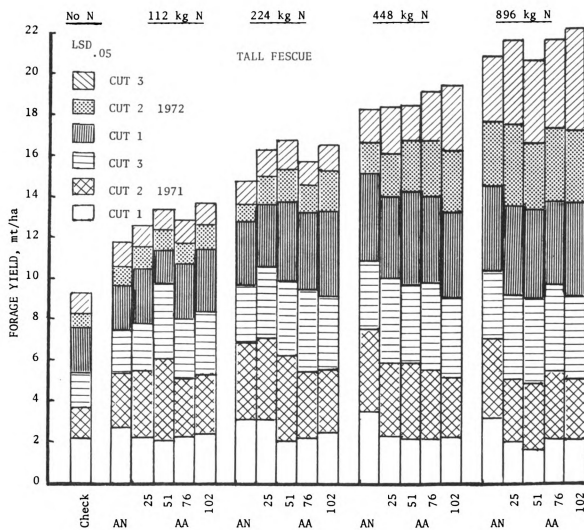


Figure 3 (cont'd.)

100

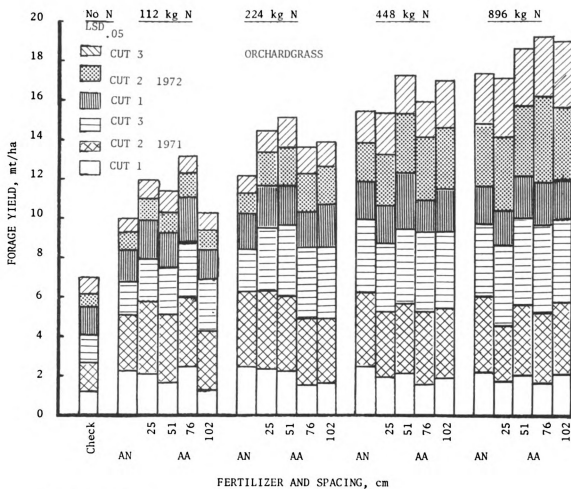


Figure 3 (cont'd.)

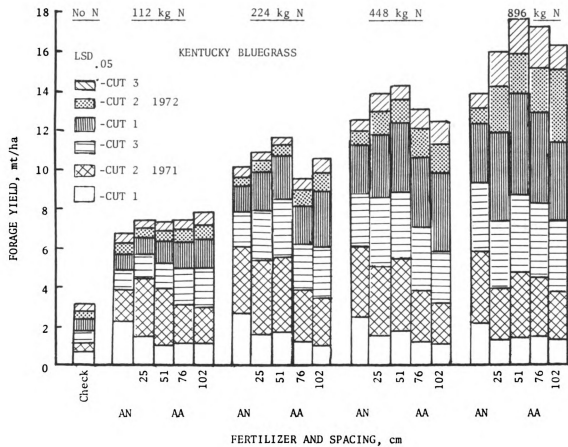


Figure 3 (cont'd.)

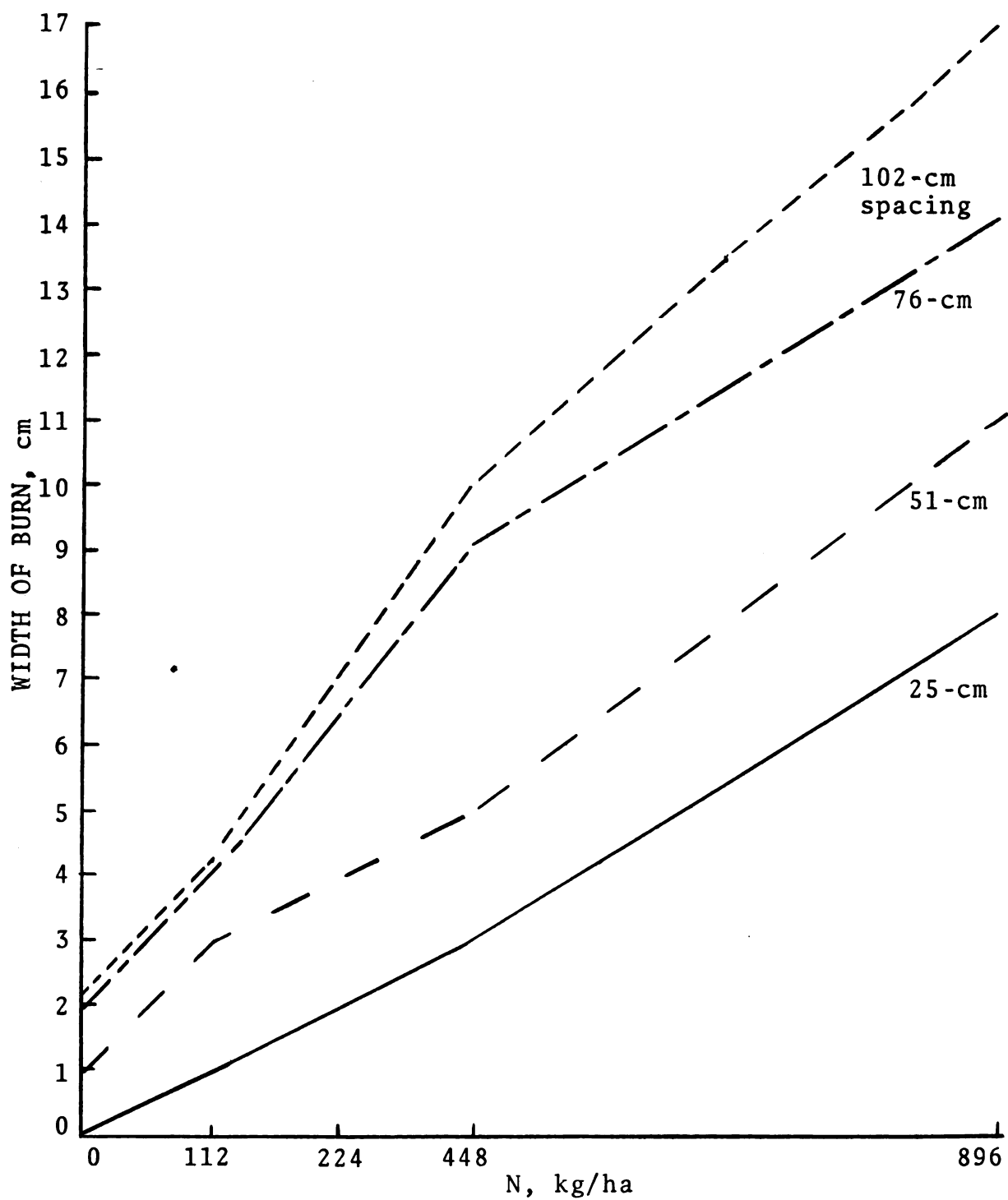


Figure 4. Average width of burn damage on foliage of brome-grass, orchardgrass, reed canarygrass, tall fescue and bluegrass over AA rows on May 23, 1971, from AA applied at four row spacings on April 29, 1971.

Table 3. Width of burn damage on grass foliage on May 23, 1971, over rows of AA applied on April 29, 1971.

Row spacing	N rate, kg/ha	BG	RC	OG	TF	KB	Avg		Avg All
							BG, RC, OG, TF		
cm		cm	cm	cm	cm	cm	cm		cm
25	112	0	0	0	2	0	1		0
	224	0	2	2	2	0	2		1
	448	0	3	2	4	5	3		3
	896	5	10	8	8	9	8		8
	Avg	1	4	3	4	4	4		3
51	112	0	0	2	2	2	1		1
	224	3	2	2	4	2	3		3
	448	3	3	3	9	5	5		5
	896	9	9	10	12	13	10		11
	Avg	4	4	4	7	6	5		5
76	112	0	4	2	2	3	2		2
	224	0	5	4	5	5	4		4
	448	8	9	8	12	9	9		9
	896	12	14	13	15	17	14		14
	Avg	5	8	7	8	8	7		7
102	112	2	2	2	2	4	2		2
	224	2	5	5	5	5	4		4
	448	9	9	7	12	14	9		10
	896	15	17	17	18	18	17		17
	Avg	7	8	8	9	10	8		8
All spacings	112	1	2	2	2	2	2		2
	224	1	4	3	4	3	3		3
	448	5	6	5	9	8	6		7
	896	10	13	12	13	14	12		12
	Avg	4	6	6	7	7	6		6



Figure 5. Burn damage on grass foliage May 10, 1971, over rows of AA applied on April 29, 1971. In the foreground is orchardgrass fertilized with 896 kg N/ha in 76-cm rows.

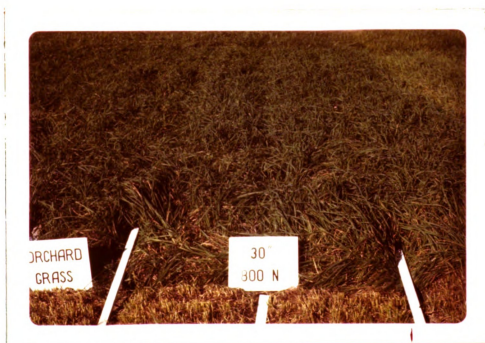


Figure 6. By October 20, 1971, orchardgrass had recovered from the burn damage of AA applied on April 29, 1971, at 896 kg N/ha in 76-cm rows.

injury six months after AA application. The grass burn from high rates of N in the wide spacings of AA and the readily available form of N in AN account for the greater yields from AN in the first cutting. Table 3 shows bluegrass and tall fescue were injured more than reed canarygrass and orchardgrass, while brome grass was least injured. This burn damage was estimated one month after AA application and did not result from discoloration at the time of AA injection. Areas of light-green grass discoloration, caused by NH_3 vapors, were observed when AA knives were removed from the sod at the end of the plots.

Second-cutting yields of all grasses (Figure 3) were highest at the 25- and 51-cm spacings at 112 and 224 kg N/ha of AA. However, yields were higher on bluegrass and tall fescue with AN than with AA in 76- and 102-cm spacings at 448 and 896 kg N. This reduction in yield with AA was attributed to burn damage being greatest on tall fescue and bluegrass.

Second - cutting yields of all grasses (Figures 3 and 7) were highest at the 25- and 51-cm spacings at 112 and 224 kg N/ha of AA. However, yields were higher on bluegrass and tall fescue with AN than with AA in 76- and 102-cm spacings at 448 and 896 kg N. This reduction in yield with AA may be attributed to burn damage being greatest on tall fescue and bluegrass.

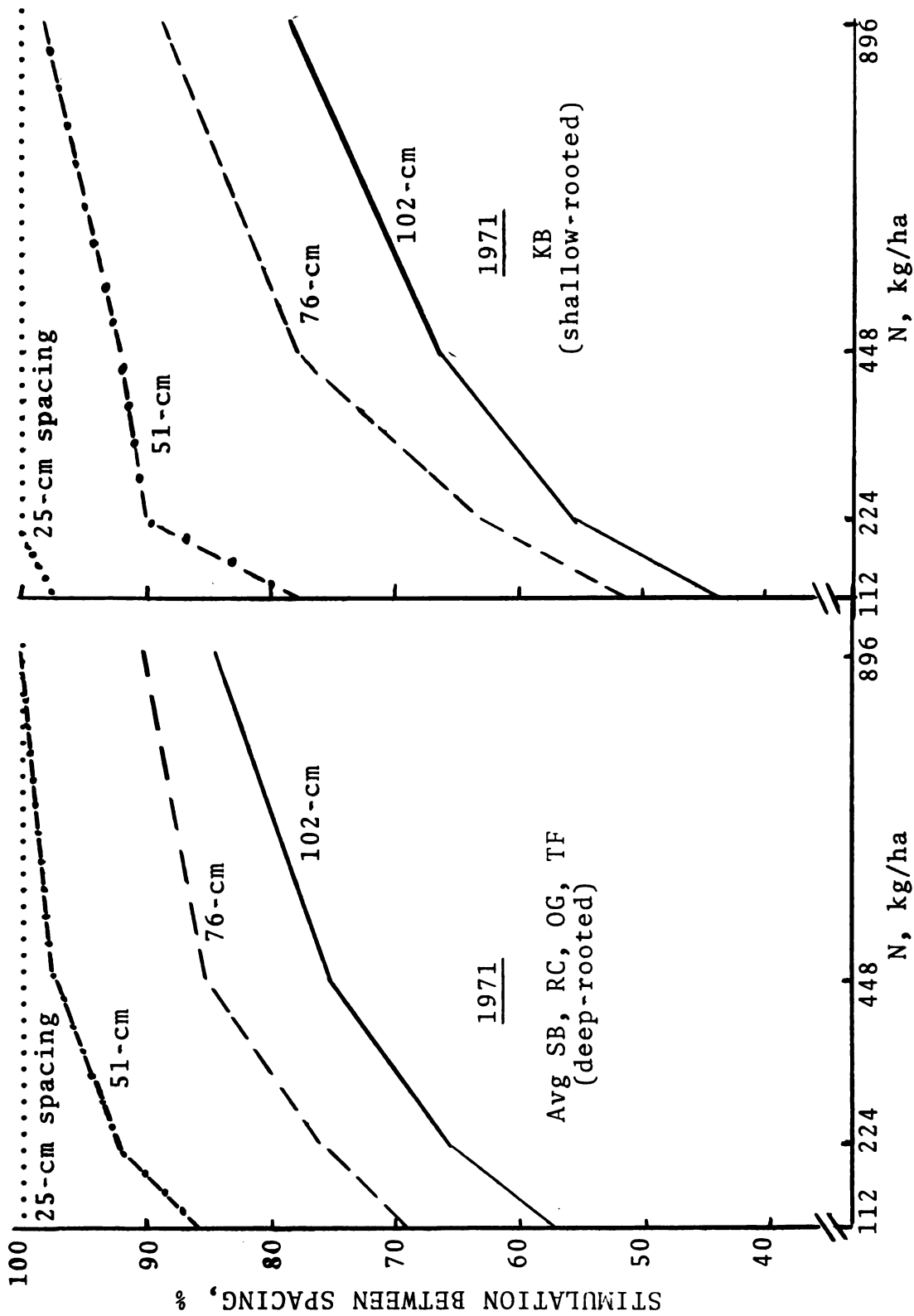


Figure 7. Average stimulation of grass by N, in percentage, rated visually at each harvest in 1971 by color and height of grasses between four row spacings of AA applied at four rates of N on April 29, 1971.

In the third cutting (Figure 3), yields were higher from AA than AN in all grasses. The deep-rooted grasses in the third cutting increased in yields as the fertilizer rate increased to the 896-kg rate. Row spacings of AA at any N level had no effect on yield, except for bluegrass. Bluegrass in the third cut had greater yields with 112 kg N in wider spacings than in narrower spacings. Grasses fertilized with AA at 76- and 102-cm spacings with 448 and 896 kg N maintained a high yield in the third cutting because of the large amounts of N.

Grass yields from AA in the first and second cuttings were usually highest at 224 kg N/ha and similar at 112 and 448 kg N/ha of AA (Figure 3). This indicates that the grasses did not require more than the 224-kg rate of N for maximum yield in the first two cuttings. The trend for increased yields at higher rates of AA was established in the third cutting since some of the applied N was used in the first two cuttings and apparently N at rates above 224 kg/ha were necessary for maximum yields.

In 1971 all spacings of AA were rated visually by color and height of grasses for stimulation of the grass between row spacings (Figure 7 and Appendix Table 1). All grasses were stimulated 100% in the 25-cm rows of AA. As the row spacing increased beyond 25 cm, the percentage stimulation decreased for all grasses, especially for bluegrass, a shallow-rooted grass (Figure 8). As the rate



Figure 8. Kentucky bluegrass on October 20, 1971, fertilized on April 29, 1971, with 224 kg N/ha as AA in 102-cm spacings (white stakes). Stimulation of shallow-rooted KB was 65% of the grass between the stakes.

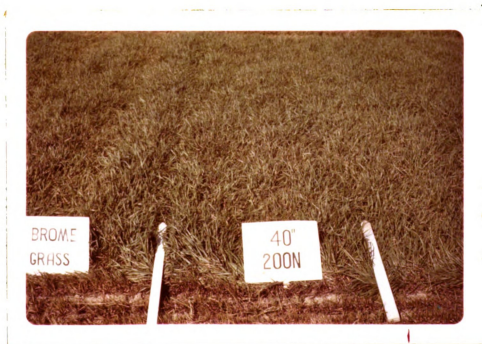


Figure 9. Smooth brome grass on October 20, 1971, fertilized on April 29, 1971, with 224 kg N/ha as AA in 102-cm spacings (white stakes). Stimulation of deep-rooted SB was 100% of the grass between the stakes.

of N increased at each row spacing of AA, percent stimulation increased markedly. The bromegrass was typical of the deep-rooted grasses, and by the third cut in 1971 showed a 100% stimulation from N applied as AA (Figure 9 and Appendix Table 2). Percentage stimulation of grasses by N between 102-cm rows of AA at the 224-kg N rate on October 20, 1971, were OG (84), SB (83), RC (76), TF (74), and KB (66) as shown in Appendix Table 2. Stimulation of the deep-rooted grasses fertilized with 224 kg N/ha in 76- and 102-cm rows was 14 and 13% higher, respectively, than the shallow-rooted bluegrass indicating that the deep-rooted grasses obtained N from a greater distance than Kentucky bluegrass. The four deep-rooted grasses had 100% of their area stimulated by N at the 448- and 896-kg/ha rates in 76-cm spacings and at the 896-kg rate in 102-cm rows. Even the short-rooted bluegrass was stimulated on 100% of the area at the maximum spacing and maximum rate of N.

Second Year (1972)

In the second year, all grasses at all rates of AA yielded more than grasses with similar rates of AN (Table 5). Yields in 1972 were lower than in 1971. The grasses ranked in the order TF = SB > RC > OG > KB in 1972. The lower yields of orchardgrass were attributed to winter injury as evidenced by depressed yields in the first cutting in 1972 (Figure 3). Winter injury was found at high rates of N in the wider spacings (Table 4).

Table 4. Injury on orchardgrass on May 9-12, 1972, in percent of the stand of grass.

N kg/ha	AN	AA, injection spacings, cm				Avg AA
		25	51	76	102	
112	3 ⁺	0	0	4 ⁺⁺	7	3
224	9 ⁺	2	4 ⁺⁺	10	11	7
448	3	11	11	40	23	21
896	25	31	42	41	34	37
Avg	10	11	14	24	19	

⁺No injury in three of four replications.

⁺⁺No injury in two of four replications.

High rates of N may have reduced carbohydrate reserves in the fall of 1971 and resulted in orchardgrass injury as suggested by Mitchell (1967) in Delaware, and by Reynolds (1969) in Tennessee. Orchardgrass fertilized with the two lowest rates of N, which did not cause serious injury to stands, had greater residual yields than reed canarygrass in 1972, except at the 102-cm spacing of AA. A dark green color of orchardgrass with 224 kg N as AA in 102-cm spacings in the first cutting in 1972 (Figure 10), showed this grass was still getting N from applied fertilizer. However, at the 112-kg rate of N as AA (Figure 10) a lighter color of orchardgrass indicated the N had been used. By July of the second year the dark color of the deep-rooted

Table 5. Second-year forage yield in 1972 in mt/ha of five grasses fertilized on April 29, 1971, with AA and with AN in split applications on May 7 and 26, June 16, and July 9 and 14, 1971.

Spacing, cm	N rate, kg/ha	Grass species					Avg SB, RC, OG, TF	Avg All
		SB	RC	OG	TF	KB		
	0	3.46	1.98	2.96	3.87	1.32	3.07	2.72
				AMMONIUM NITRATE				
	112	3.80	2.45	3.30	4.28	1.72	3.46	3.11
	224	4.54	3.27	3.63	5.11	2.30	4.14	3.77
	448	8.15	5.84	5.35	7.34	3.76	6.67	6.09
	896	10.28	9.63	7.62	10.51	4.62	9.51	8.53
	Avg	6.69	5.30	4.98	6.81	3.10	5.96	5.38
LSD .05								
Two grasses within a N rate = 0.68 ⁺ N rates within a grass(es) = 0.67 ⁺								
				ANHYDROUS AMMONIA				
25	112	4.20	3.03	4.02	4.85	1.81	4.03	3.58
	224	6.13	4.58	4.97	5.67	2.93	5.34	4.86
	448	8.88	7.26	6.63	8.39	5.30	7.79	7.29
	896	11.87	12.70	8.58	12.59	8.54	11.44	10.86
	Avg	7.77	6.89	6.05	7.88	4.65	7.15	6.65
51	112	4.22	3.37	3.83	4.63	2.17	4.01	3.64
	224	6.80	4.52	5.51	6.92	3.19	4.94	5.39
	448	8.77	7.82	7.82	8.91	5.40	8.33	7.74

76	896	12.57	11.78	8.66	11.59	9.04	11.15	10.73
	Avg	8.09	6.87	6.46	8.01	4.95	7.36	6.87
	112	4.55	2.82	4.55	4.82	2.47	4.19	3.84
	224	6.20	4.59	4.99	6.25	3.37	5.51	5.08
102	448	8.60	8.89	6.57	9.48	5.89	8.39	7.89
	896	12.10	12.08	9.54	11.99	8.96	11.43	10.93
	Avg	7.86	7.10	6.41	8.14	5.17	7.38	6.94
	112	5.57	3.81	3.45	5.32	2.93	4.54	4.22
LSD .05	224	7.39	5.39	5.31	7.30	3.84	6.35	5.85
	448	10.64	9.07	7.64	10.49	6.63	9.44	8.87
	896	13.72	12.27	9.09	13.10	8.82	12.05	11.40
	Avg	9.31	7.64	6.37	9.05	5.56	8.09	7.59
Two grasses within a spacing and a N rate = 1.13 ⁺								
Spacings within a grass(es) and a N rate = 1.14 ⁺								
N rates within a spacing and a grass(es) = 1.01 ⁺								
All	112	4.64	3.26	3.96	4.91	2.35	4.19	3.82
	224	6.63	4.77	5.20	6.54	3.33	5.85	5.30
	448	9.20	8.26	7.17	9.32	5.81	8.49	7.95
	896	12.57	12.21	8.97	12.32	8.83	11.52	10.98
	Avg	8.26	7.13	6.32	8.27	5.08	7.50	7.01

⁺Value for comparing any two grasses.



Figure 10. Orchardgrass on May 25, 1972, fertilized on April 29, 1971, with AA in 102-cm rows. The grass has used all the N at the 112-kg rate, but not all the N at the 224-kg rate.

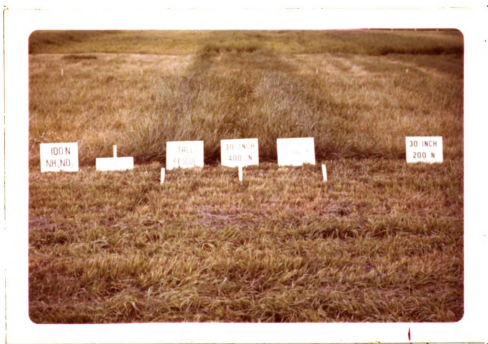


Figure 11. Tall fescue on July 9, 1972, fertilized on April 29, 1971, with AA in 76-cm rows. The grass has used all the N from AA at the 224-kg rate, but not all the N at the 448-kg rate.

tall fescue indicated N was still available from the 448-kg rate as AA, but not from the 224-kg N rate (Figure 11).

Average 1972 residual yields from AA (over all spacings) at 112, 224, 448 and 896 kg N/ha were 22, 41, 31 and 29% greater, respectively, than from AN (Table 5). Yields for most rates of N and most grasses were similar at the 25-, 51-, and 76-cm spacings. Yields were greater, however, as the row spacings of AA increased.

All five grasses had some residual effect from the 112 kg N applied in the previous year as AN, but the increase averaged only about 14% above the check. With AA, however, the increase ranged from 31% at the 25-cm spacing to 55% at the 102-cm spacing of AA. The relative increase was greater for bluegrass than for any of the deep-rooted grasses, with the greatest increase being at the widest spacing.

The 1972 visual ratings by color and height of grasses on AA-fertilized plots as an indication of N stimulation is presented in Figure 12 and Appendix Table 1. The percentage of the grasses which were stimulated by N increased as N levels increased and as row spacings decreased. Maximum stimulation of 100% was in 25-cm spacings at the maximum rate of 896 kg N/ha. Minimum stimulation of 30% for bluegrass and 35% of the four tall grasses was obtained at the lowest rate of N in the widest spacing. Deep-rooted grasses were stimulated more than bluegrass, the short-rooted grass.

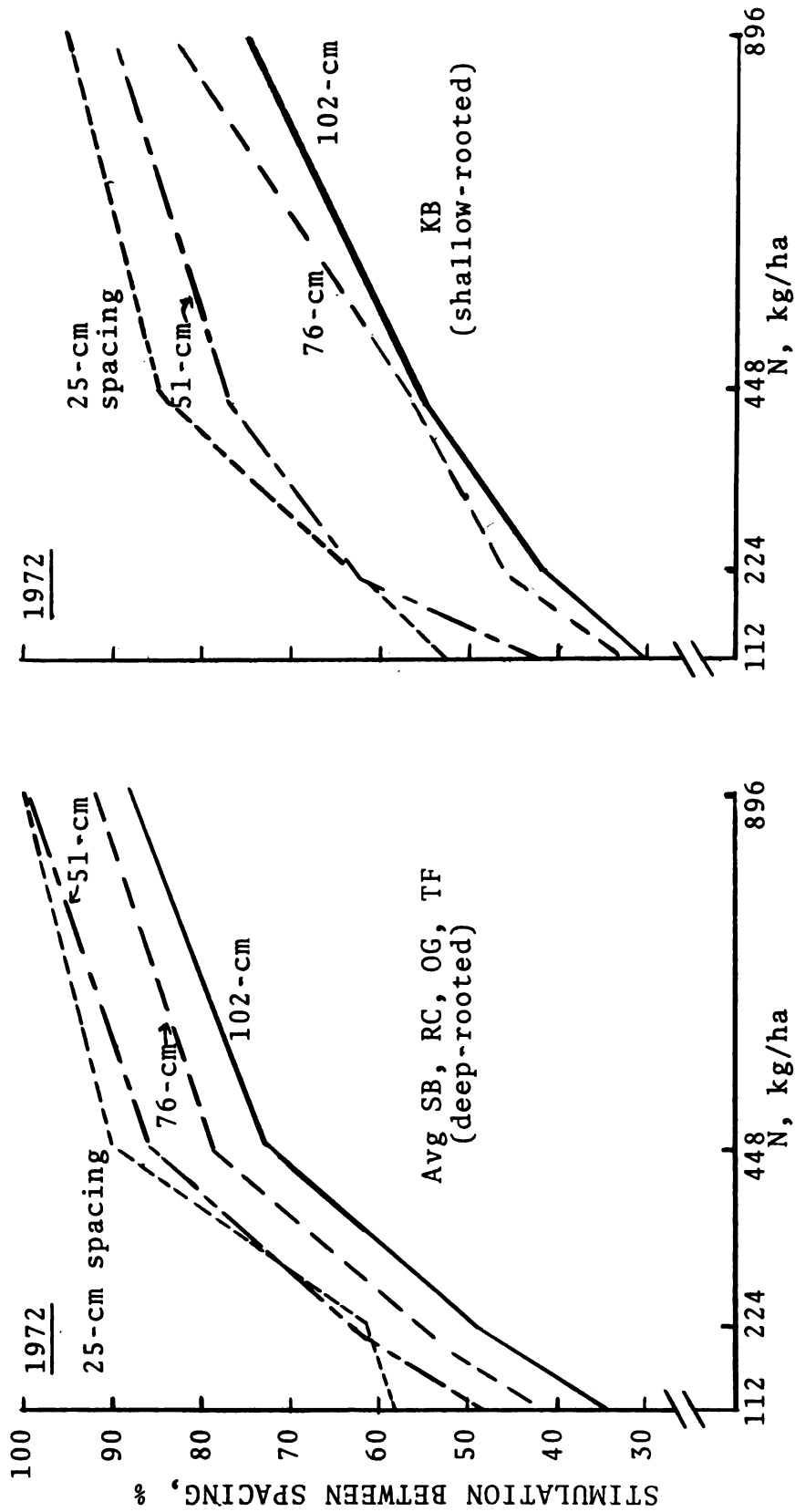


Figure 12. Average stimulation of grass by N, in percentage, rated visually at each harvest in 1972 by color and height of grasses between four row spacings of AA applied at four rates of N on April 29, 1971.

Yields in the second year continued to increase as rates of N increased from 112 to 896 kg, but the increase was larger with AA than AN, especially at the highest rate of N. This indicated the grasses were using more N from AA than from AN. In several replications of bluegrass a N deficiency as indicated by a light green grass color with 896 kg AN was seen by the third cutting in 1972. All bluegrass fertilized with 896 kg N as AA, however, had a dark green color by the third cutting in 1972. This indicated that not all N from AA had been used previously by the grass.

Total Two Years

Total effect of N was determined by combining 1971 and 1972 yields of the grasses fertilized only in 1971. The averages of the grass yields for the four deep-rooted grasses were similar for all four spacings of AA at each level of N (Table 6). It was surprising that the 102-cm spacing was as effective as the narrow spacings in its effect on two-year total yields for the deep-rooted grasses. The short-rooted bluegrass, however, was significantly lower in yield in the 76- and 102-cm rows at all N levels except at the lowest rate of 112 kg/ha. This is seen in Figures 7, 8, and 12 which show that bluegrass was not stimulated to as great a distance from the AA row as the deep-rooted grasses in the wider row spacings. The AA applied

Table 6. Two-year total of forage yield in mt/ha of five grasses in 1971 and 1972 when fertilized on April 29, 1971, with AA and with AN in split applications on May 7 and 26, June 16, July 9 and 14, 1971.

Spacing, cm	N rate, kg/ha	Grass species					Avg	
		SB	RC	OG	TF	KB	SB, RC, OG, TF	Avg All
	0	12.13	5.85	7.15	9.36	3.09	8.62	7.52
		AMMONIUM NITRATE						
	112	14.32	9.91	10.13	11.87	6.64	11.56	10.57
	224	17.22	13.44	12.25	14.90	10.07	14.45	13.58
	448	21.62	16.68	15.55	18.37	12.54	18.06	16.95
	896	24.29	21.07	17.45	21.04	13.83	20.96	19.54
	Avg	19.36	15.28	13.85	16.55	10.77	16.56	15.16
LSD .05								
Two grasses within a N rate = 0.87 ⁺								
N rates within a grass(es) = 0.67 ⁺								
		ANHYDROUS AMMONIA						
25	112	16.34	11.38	12.02	12.72	7.42	13.12	11.98
	224	19.81	14.47	14.64	16.42	10.79	16.34	15.23
	448	21.90	17.13	15.53	18.53	13.85	18.27	17.39
	896	22.05	21.28	17.35	21.83	15.87	20.63	19.68
	Avg	20.03	16.07	14.89	17.38	11.98	17.09	16.07
51	112	16.69	12.06	11.54	13.55	7.34	13.46	12.24
	224	20.58	14.79	15.31	16.87	11.59	16.89	15.83
	448	21.71	18.12	17.43	18.62	14.21	18.97	18.02
	896	23.80	21.40	18.77	20.80	17.61	21.19	20.48
	Avg	20.70	16.59	15.76	17.46	12.69	17.63	16.64

76	112	16.55	11.16	13.35	12.95	7.37	13.50	12.28
	224	18.14	13.44	13.77	15.81	9.43	15.29	14.12
	448	21.72	18.66	16.14	19.30	12.95	18.96	17.75
	896	24.95	21.79	19.44	21.84	17.20	22.01	21.04
	Avg	20.34	16.26	15.68	17.48	11.74	17.44	16.30
102	112	16.47	11.77	10.41	13.76	7.80	13.10	12.04
	224	19.73	13.56	14.07	16.62	9.84	16.00	14.76
	448	23.35	17.44	17.17	19.61	12.39	19.39	17.99
	896	25.24	21.39	19.18	22.43	16.22	22.06	20.89
	Avg	21.20	16.04	15.21	18.11	11.56	17.64	16.42
LSD .05	Two grasses within a spacing and a N rate = 1.13 ⁺ Spacings within a grass(es) and a N rate = 0.97 ⁺ N rates within a spacing and a grass(es) = 0.98 ⁺							
						--	--	--
						0.47	0.47	0.42
						0.25	0.25	0.22
All	112	16.51	11.59	11.83	13.25	7.48	13.30	12.14
	224	19.57	14.06	14.48	16.43	10.41	16.13	14.99
	448	22.17	17.84	16.57	19.02	13.35	18.90	17.79
	896	24.01	21.47	18.69	21.73	16.72	21.47	20.52
	Avg	20.57	16.24	15.39	17.61	11.99	17.45	16.36

⁺Value for comparing any two grasses.

in wider spacings requires fewer knives on the injection equipment to cover the same grass area. Fewer knives meant each knife was more efficient per unit land area.

All grasses increased in yield as N increased to the 896-kg N rate (Table 6). With AA, the grasses had a consistently higher yield than with AN. The increases, however, were small. For the four deep-rooted grasses, the increases favoring AA were 5, 12, 5, and 2% of the 112-, 224-, 448-, and 896-kg rates of N, respectively (Figure 13). The 19% lower yield of bluegrass at the high rate of N as AN in contrast to AA was due largely to a considerably lower second-year yield with AN than with AA (Figure 14). Bluegrass was not getting the N from AN late in the second year because most of the N was leached below its root zone (see Section III). The deep-rooted grasses, however, were getting the N from AN in the second year, even in the third cutting at the highest rate of N, as indicated by their high yields. Maximum root depths determined in the fall of the second year under a N rate of 224 kg/ha were as follows: tall fescue = 132 cm, > brome grass = 122 cm, > reed canarygrass = 102 cm, > orchardgrass = 89 cm, > bluegrass = 76 cm.

Grasses yielded in the order of brome grass > tall fescue > reed canarygrass > orchardgrass > bluegrass, (Table 6). Brome grass was higher yielding than the other deep-rooted grasses at the various spacings of N as AA and

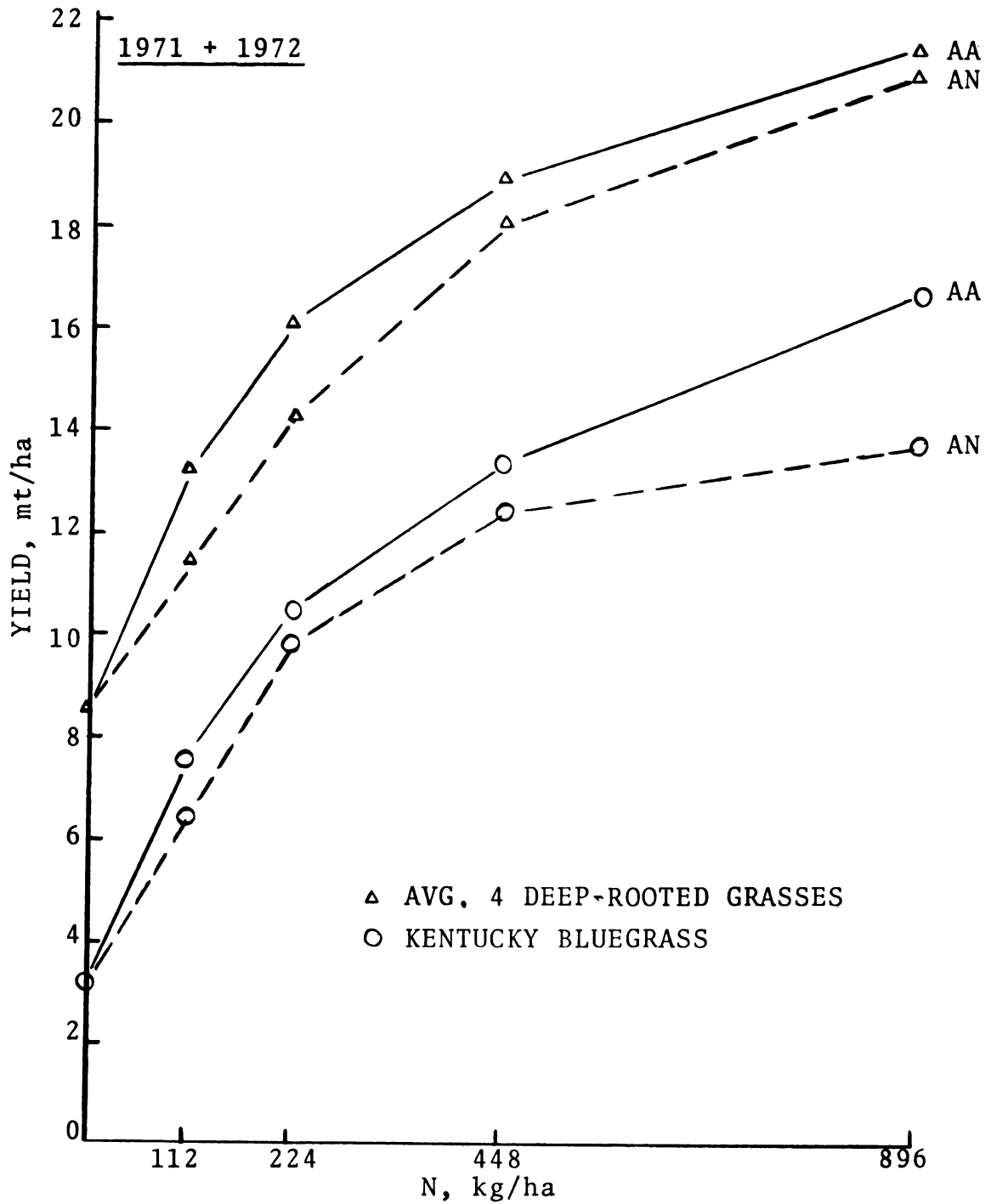


Figure 13. Two-year yields of grasses fertilized on April 29, 1971, with AA (average of 25-, 51-, 76-, and 102-cm row spacings) and with AN in split applications May 7 to July 14, 1971.

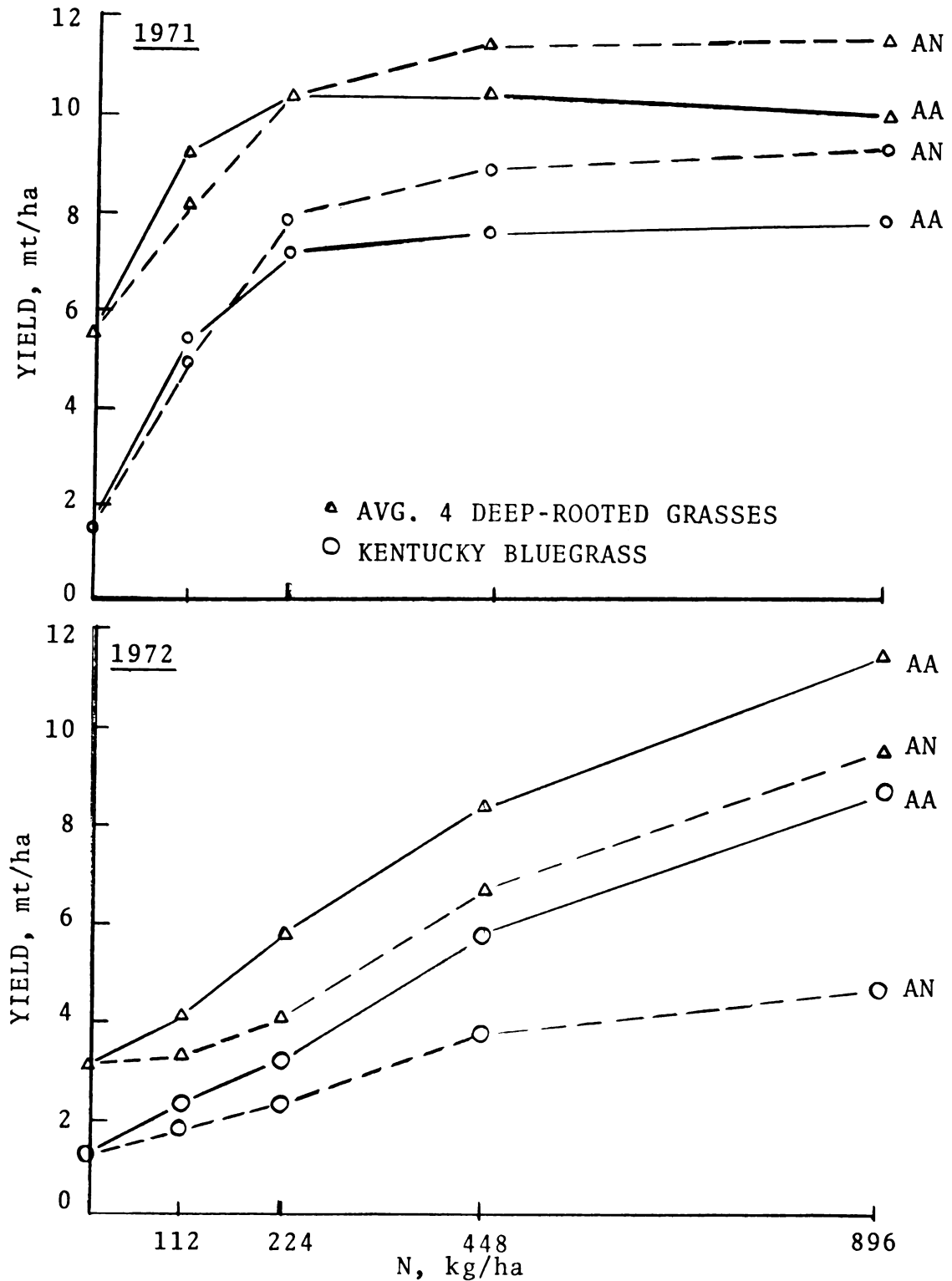


Figure 14. First- and second-year yields of shallow- and deep-rooted grasses fertilized on April 29, 1971, with AA (average of 25-, 51-, 76-, and 102-cm row spacings) and with AN in split applications May 7 to July 14, 1971.

at varying rates of N with either source of N. The shallow-rooted bluegrass always had lowest yields. The four deep-rooted grasses yielded an average of 47% more than bluegrass. Winter injury to orchardgrass reduced yields in the second year at high N rates and contributed to lower two-year average yields than previous results in Michigan indicated (Tesar, 1972).

Individual year comparisons in Figure 14 show grass yields were higher from AA than AN in 1971 and 1972 with 112 kg N, because more residual N was available for the grasses. In 1971 yields did not increase with AA at rates of N greater than 224 kg/ha, while AN continued to increase yields up to a rate of 448 kg of applied N. The grasses over the entire fertilized area used the readily available nitrate from AN early in the first season. However, AA was concentrated in row spacings where it injured grass roots (when applied in high rates) but gradually became available to the grasses as nitrification proceeded and roots of grasses recovered. Grasses fertilized with AA had highest yields at all N rates and spacings in the third cutting in 1971 (Figure 3), and in all cuttings in 1972. In 1972, increased yields with AA and AA were almost linear for the deep-rooted grasses as rates increased from 112 to 896 kg N (Figure 14). Increases were greater with AA than AN, however, so that even though first-year yields at the two highest levels of AN were greater than with

AA, total two-year yields were somewhat greater with AA (Figure 13) as discussed earlier.

In general, the four tall deep-rooted grasses reacted similarly to increases in N fertilizer and increases in row spacings with some minor exceptions such as those attributed to winter injury of orchardgrass (Table 5). Kentucky bluegrass reacted similarly to the two sources of fertilizer with the exception of a considerably lower yield from AN than from AA at the highest rate of N as indicated above. In every comparison, each grass at every rate of N produced a higher percentage of the first-year's yield in the first cutting when fertilized with AN than with AA, indicating more available N from the AN source, in the approximate 5- to 6-week period after application (Table 7).

Table 7. Seasonal percentage yield distribution of five grasses.

N Rate, Year kg/ha	Smooth brome grass cut			Reed canary grass cut			Orchard- grass cut			Tall fescue cut			Kentucky bluegrass cut			Avg SB, RC, OG, TF, cut			Avg All grasses cut			
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
0	71	79	11	10	50	34	16	30	37	33	43	27	30	38	30	32	50	27	22	50	28	24
72	72	72	16	12	52	28	20	48	25	27	57	19	24	47	28	26	57	22	21	55	23	22
AMMONIUM NITRATE																						
112	71	68	20	12	48	38	14	35	40	25	37	35	28	45	34	21	47	33	20	47	33	20
72	72	74	15	11	50	28	22	48	27	25	55	21	24	44	26	30	57	23	20	55	23	22
224	71	53	33	14	40	46	15	31	44	26	33	39	28	33	43	24	39	41	20	38	41	21
72	72	78	14	8	64	20	16	48	27	25	60	18	22	57	23	20	63	20	17	61	20	19
448	71	56	26	18	36	39	25	26	37	37	33	36	31	29	40	31	38	35	27	36	36	28
72	72	78	15	7	63	25	12	35	37	28	59	20	21	66	19	15	59	24	17	60	23	17
896	71	53	29	18	38	37	25	25	38	37	32	37	31	23	40	37	37	35	28	34	36	30
72	72	54	26	20	45	37	18	24	42	34	40	30	30	65	17	18	41	34	25	46	30	24
Avg	71	58	27	15	40	40	20	29	40	31	34	37	29	32	40	28	40	36	24	39	36	25
72	72	71	17	12	55	28	17	39	33	28	54	22	24	58	21	21	55	25	20	56	24	20

ANHYDROUS AMMONIA

112	71	56	30	14	33	49	18	26	43	31	28	39	33	22	47	31	36	40	24	33	42	25
	72	71	19	10	59	26	15	48	27	25	57	22	21	52	27	21	59	23	18	57	24	18
224	71	52	30	18	27	48	25	23	39	38	26	37	37	21	43	36	32	39	29	30	39	31
	72	71	21	8	65	24	11	38	36	26	57	23	20	64	22	14	58	26	16	59	25	16
448	71	53	26	21	25	46	29	22	37	41	24	35	41	18	39	43	31	36	33	28	37	35
	72	60	27	13	54	33	13	30	41	29	45	28	27	61	23	16	47	32	21	50	30	20
896	71	49	26	25	25	44	31	21	35	44	23	33	44	17	36	47	30	35	35	27	35	38
	72	50	30	20	43	37	20	22	43	35	35	29	36	51	27	22	38	34	28	40	33	27
Avg	71	53	28	19	27	47	26	23	38	39	25	36	39	20	41	39	32	38	30	30	38	32
	72	63	24	13	55	30	15	34	37	29	48	26	26	57	25	18	50	29	21	52	28	20

SECTION II

PLANT NITRATES

A. Literature Review

Nitrogen (N) fertilization produces high grass yields, distributes the yield throughout the season, and increases the content of nitrate-N in the grass foliage as reported by George et al. (1972) in Indiana, Kennedy (1960) in New York, Look Kin and MacKenzie (1970) in Quebec, and Reynolds, Lewis, and Laaker (1971) in Tennessee. Nitrate-N is an important chemical constituent to consider in forage quality because it is reduced by ruminant microorganisms to the toxic nitrite form which easily permeates intestinal walls and enters the blood (Wright and Davison, 1964).

Lethal amounts of nitrite from nitrate in the rumen or stomach vary with species, age and physiological status of the animal, type of ration, and the amount of feed in the rumen at any one time. Sublethal concentrations in the 0.07 to 0.20% (700 to 2000 ppm) nitrate-N range have caused decreased milk production, abortion, and loss of weight as reported by Hill and Ackerson (1964) in Nebraska, Crawford, Kennedy, and Wright (1960) and Wright and

Davison (1964) in New York. Ryan, Wedin, and Bryan (1972) in Iowa considered 0.15% nitrate-N safe for four perennial grasses based on the report of Wright and Davison (1964). Smith (1967) in Missouri reported 0.11% nitrate-N to be a safe concentration, while 0.40% nitrate-N in forage was considered potentially fatal to livestock.

Wright and Davison (1964), Crawford, Kennedy, and Johnson (1961), and Crawford, et al. (1960) listed drought, low light conditions, growth inhibitors, and high soil N as contributing factors to high grass nitrate-N accumulation. They also emphasized species, part of the plant, nitrate reductase activity, and stage of maturity as important internal factors that had an effect on nitrate-N concentrations in grass. Bluegrasses were considered non-accumulators of nitrate-N. Highest concentration of nitrate-N was usually in the stem, especially lower internodes, with less nitrate-N in the leaves, and least nitrate-N in the floral parts. Mature grass, when accompanied by a large dry matter increase, had a low level of nitrate-N.

Nitrate-N accumulation has been reported for solid fertilizer applications on smooth brome grass (Bromus inermis Leyss.), Smith and Lund (1965), Look Kin and MacKenzie (1970), Murphy and Smith (1967), Ryan, et al. (1972), Hill and Ackerson (1964), orchardgrass (Dactylis glomerata L.), Dotzenko and Henderson (1964), Murphy and

Smith (1964), apGriffith and Johnston (1960), Ryan, et al. (1972), and Reynolds, Lewis, and Laaker (1971), tall fescue (Festuca arundinacea Schreb.), Murphy and Smith (1967), apGriffith and Johnston (1960), Ryan, et al. (1972), George, et al. (1972), and Hojjati, Taylor, and Templeton (1972), reed canarygrass (Phalaris arundinacea L.), Ryan, et al. (1972), and Kentucky bluegrass (Poa pratensis L.), Madison (1972). However, little information is available on accumulation of nitrate-N in perennial grasses fertilized with anhydrous ammonia. Lechtenberg, et al. (1970) in Indiana reported anhydrous ammonia gave lower "high levels of nitrate" than similar N rates as ammonium nitrate. They noted no adverse effects on animal performance from nitrate-N levels as high as 0.30% in brome grass and orchardgrass.

The objective of this section of the study was to determine the effect of four rates and four row spacings of anhydrous ammonia on the accumulation of nitrate-N in five perennial grasses.

B. Materials and Methods

The establishment of stands of orchardgrass (OG), reed canarygrass (RC), smooth brome grass (SB), tall fescue (TF), and Kentucky bluegrass (KB) and the application of anhydrous ammonia (AA and ammonium nitrate (AN) were described in Section I-B, Materials and methods. Average

monthly air and soil temperatures and precipitation and irrigation added were included in Section I-B.

A combined leaf and stem sample from each grass was taken on June 10 and July 23, 1971, on four replications, and on May 25 and July 21, 1972, on three replications on the following:

Check

112 kg N as AN and AA in 25- and 76-cm rows

224 kg N as AN and AA in 25- and 76-cm rows

448 kg N as AN and AA in 25- and 76-cm rows

896 kg N as AN and AA in 25-, 51-, 76-, and 102-cm rows.

Samples were taken one or two days before forage harvests.

The range of height and stage of maturity of each grass in the first harvest on May 23, 1971, and on May 25, 1972, are shown in Table 8. Grasses were similar in maturity in 1971 and 1972, but varied in height. Height was greatly influenced by rates of nitrogen.

Each foliage sample was composed of five sub-samples selected at random 5 cm on either side of AA rows within each plot of grass. On grasses fertilized with AN and on check plots, the samples were chosen at random within each 1.9 x 9.1 m plot. A composite sample was wrapped tightly in a cellophane bag and transported in dry ice to a freezer where the samples were kept at 5 C until analyzed.

Table 8. Maturity and height of grasses.

Species	May 23, 1971		May 25, 1972	
	Stage	Height, cm	Stage	Height, cm
Smooth brome grass	Early boot	30-41	Late boot- heading	23-64
Reed canary grass	Early boot	20-26	Early boot	13-64
Orchard grass	Late boot- heading	22-29	Heading	20-46
Tall fescue	Late boot- heading	20-26	Late boot- heading	25-46
Kentucky blue grass	Heading	13-18	Late boot- heading	5-15

Nitrate-N was determined by the nitrate electrode method described by Paul and Carlson (1968) and modified by use of a saturated calcium sulfate solution (in place of an aluminum resin) to maintain a high pH and remove interfering anions in the solution. A 10.0-g sample of frozen leaf and stem material was homogenized in 100 ml of a saturated calcium solution in a waring blendor set at full speed for one minute. Longer intervals of blending samples were found to only slightly improve analyses. The homogenized material was passed through cheesecloth before a determination was made on a sample. Nitrate results are reported on a dry weight basis as nitrate-nitrogen (nitrate-N). Field dry weight determinations from the forage cuts on the same plots were used because these determinations of dry matter were from 1000-g samples.

C. Results and Discussion

First Year (1971)

The effect of AA and AN sources of nitrogen on the percentage of nitrate-N of five grasses in 1971 is shown in Table 9. All grasses increased in nitrate-N from June to July with greatest increases with highest amounts of applied N. The average level of accumulation on June 10 and July 23 was in the order of OG > TF = RC = SB > KB, although reed canarygrass at high rates of N accumulated more nitrate-N than tall

Table 9. Effect of N source on percent⁺ nitrate-N of five grasses in 1971. (Dry weight basis)

Spacing, cm	N rate, kg/ha	OG		SB		RC		TF		Avg OG, SB, RC, TF		KB		Avg All	
		June 10	July 23	June 10	July 23	June 10	July 23	June 10	July 23	June 10	July 23	June 10	July 23	June 10	July 23
		10	23	10	23	10	23	10	23	10	23	10	23	10	23
0		.014	.026	.008	.021	.017	.043	.014	.041	.016	.033	.010	.016	.013	.029
AMMONIUM NITRATE															
112		--	.028	--	.025	--	.032	--	.035	--	.030	--	.016	--	.027
224		.073	.149	.049	.114	.045	.108	.038	.163	.051	.134	.011	.033	.043	.113
448		.410	.453	.188	.214	.263	.287	.164	.297	.256	.263	.126	.096	.230	.229
896		--	.730	--	.372	--	.504	--	.422	--	.507	--	.235	00	.453
Avg		.242	.340	.119	.181	.154	.233	.101	.229	.157	.237	.069	.095	.137	.206
LSD .05															
Two grasses within a N rate = .100 ⁺⁺ (6/10); .209 ⁺⁺ (7/23)															
N rates within a grass(es) = .096 ⁺⁺ (6/10); .191 ⁺⁺ (7/23)															
ANHYDROUS AMMONIA															
25		.113	.092	.062	.068	.042	.085	.076	.107	.073	.088	.017	.022	.062	.073
224		.189	.231	.072	.182	.072	.141	.082	.239	.104	.198	.028	.077	.089	.174
448		.321	.512	.117	.270	.099	.339	.112	.268	.162	.347	.034	.102	.137	.298
896		.325	.667	.151	.341	.141	.362	.157	.269	.194	.410	.043	.197	.163	.367
Avg		.237	.376	.101	.215	.089	.232	.107	.221	.133	.261	.031	.100	.113	.229

76	112	.157	.181	.060	.155	.066	.119	.069	.200	.088	.164	.024	.080	.075	.147
	224	.193	.299	.060	.138	.064	.137	.058	.236	.080	.203	.018	.083	.068	.179
	448	.212	.309	.078	.204	.061	.205	.065	.238	.104	.239	.026	.106	.088	.212
	896	.205	.629	.079	.410	.090	.358	.065	.334	.109	.341	.035	.167	.095	.306
	Avg	.192	.355	.069	.227	.070	.205	.064	.252	.095	.237	.026	.109	.082	.211
25 and 76	112	.135	.137	.061	.112	.054	.102	.073	.154	.081	.126	.021	.051	.069	.082
	224	.191	.265	.066	.160	.068	.139	.070	.238	.092	.201	.023	.080	.079	.177
	448	.267	.411	.098	.340	.080	.272	.089	.253	.133	.293	.030	.104	.113	.255
	896	.265	.648	.115	.376	.116	.360	.111	.302	.152	.376	.039	.182	.129	.337
LSD	Avg	.214	.365	.085	.247	.080	.218	.086	.237	.115	.249	.028	.104	.098	.213
.05															
Two grasses within a spacing and a N rate = .090 ⁺⁺															
(6/10); .205 ⁺⁺ (7/23)															
Spacings within a grass(es) and a N rate = .087 ⁺⁺															
(6/10); .147 ⁺⁺ (7/23)															
N rates within a spacing and a grass(es) = .068 ⁺⁺															
(6/10); .217 ⁺⁺ (7/23)															
51	896	.189	.701	.089	.297	.066	.368	.092	.382	.109	.437	.036	.213	.094	.392
102	896	.175	.664	.049	.331	.055	.332	.065	.326	.086	.413	.028	.147	.074	.360

⁺Four replications.

⁺⁺Value for comparing any two grasses on a sampling date.

fescue. These levels of nitrate-N in AN fertilized grasses are similar to levels reported by Murphy and Smith (1967) in Missouri and Ryan, et al. (1972) in Iowa. Levels of nitrate-N were relatively similar as row spacing of AA increased from 25 to 76 cm. Nitrate-N percentages were higher with AN than with AA six weeks after application in most instances. Twelve weeks after application, however, nitrate-N levels were higher in all grasses with AA at lower rates of 112 and 224 kg N, nearly equal with both N sources at 448 kg N, but higher with AN at the 896-kg rate (Figure 15).

Hazardous levels of nitrate-N for ruminant animals were reported to be 0.15% (1500 ppm) nitrate-N by Wright and Davidson (1964) in New York, and were considered potentially dangerous in this study. It must be considered that the high percentage of nitrate-N shown in Figure 15 was in grass sampled a 5-cm distance from AA rows. Grass midway between AA rows was getting less N. Therefore, a mixture of the low and high nitrate-N grasses at the time of forage cutting represented a "safety factor" because ruminant animals would probably not consume forage consisting only of high nitrate-N plants.

Six weeks (June 10) after AA was applied, no dangerous levels of nitrate-N were found in brome grass, reed canarygrass, and bluegrass (Table 9). Orchardgrass, however, had safe nitrate-N levels only with 25-cm AA

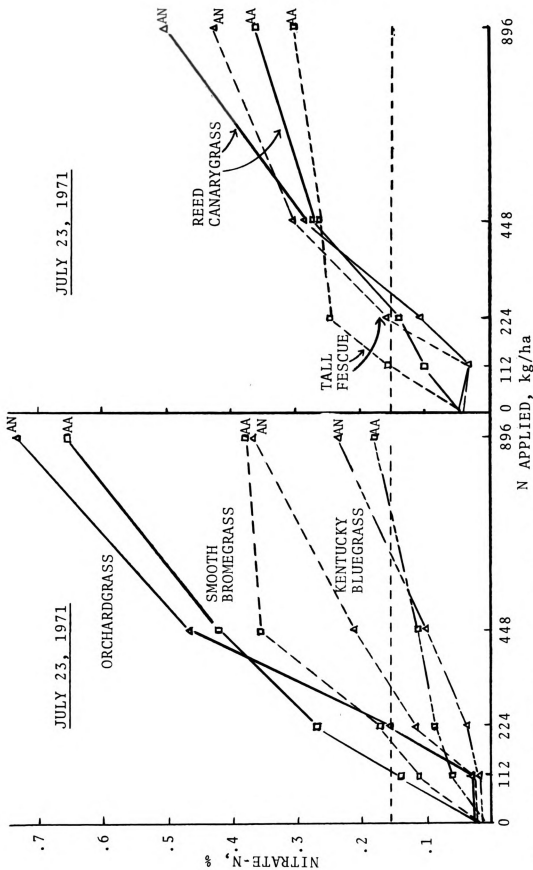


Figure 15. Nitrate-N content of orchardgrass, smooth brome grass, Kentucky bluegrass, reed canarygrass, and tall fescue fertilized with AA on April 29, 1971, and with AN in split applications on May 7 and 26, June 16, July 9 and 14, 1971. Nitrate-N content is an average of 25- and 76-cm AA row spacings. The 0.15% level is indicated as being potentially dangerous to livestock. (Sampled 5 cm away from the point of AA application.)

rows and 112 kg N, while tall fescue was potentially dangerous with 896 kg N/ha. All grasses fertilized with AN were considered safe at 112 and 224 kg N/ha, but only bluegrass was safe at the two highest rates of AN.

Twelve weeks (July 23) after AA was applied (Figure 15), bromegrass and, to a lesser extent, reed canarygrass were still the lowest in nitrate-N with bromegrass having safe levels at rates of N below 896 kg N and reed canarygrass having safe levels below the 448-kg rate. Orchardgrass still had the most nitrate-N with safe amounts only at the lowest N rate of 112 kg.

Accumulation of nitrate-N was greater in grasses at the lower N rates as AA than as AN because the selected sample near the AA row was near a higher concentration of nitrate-N from nitrified NH_4^+ than when AN was applied broadcast. At the highest rates of N, the nitrate-N levels were higher in AN-treated grasses because of a greater concentration of available nitrate-N than in grass fertilized with AA which had less of its N in the nitrate form. Eno and Blue (1957) have shown that NH_4^+ is nitrified to nitrate-N and accumulates in a zone around the N source. This higher percentage of nitrate-N in grasses with AN than with AA agrees with Lechtenberg, et al. (1970) in Indiana where they reported the same finding with orchardgrass and bromegrass fertilized with 500 kg N.

The high N rates on grasses and a dry, warm period through June and July contributed to high nitrate-N concentration. Irrigation on June 20 and good rains in late July, 1971 likely stimulated the uptake of soil nitrate-N. Nitrate-N accumulated in the grasses when the plants were growing rapidly because the plants were unable to convert all the nitrate-N to other forms of nitrogen.

Soil profiles were high in nitrate-N under the higher N rates of AN and at all rates of AA in 76-cm rows as determined by soil tests (see Section III). Higher grass yields with AN than with AA in the first cutting on June 11 accounted for the greater removal of N from the soil and correspondingly lower plant nitrate-N levels. By July 23, 1971, the grasses fertilized with 112 kg N as AN had similar or lower levels of nitrate-N than the checks because soil nitrate-N from AN was depleted. The last 224 kg of the 896-kg N split application of AN was applied on July 14, and accounted for the higher level of plant nitrate-N with AN than with AA at the highest N rate shown in Figure 15.

Second Year (1972)

Nitrate-N levels were lower on all grasses in 1972 than in 1971 (Table 10), and high levels approaching the 0.15% critical level in 1972 were found only at the two highest rates of N. Percentages of nitrate-N in 1972

Table 10. Effect of N source on percent⁺ nitrate-N of five grasses in 1972. (Dry weight basis.)

Spacing, cm	N rate, kg/ha	OG		SB		RC		TF		Avg OG, SB, RC, TF		KB		Avg All	
		May 25	July 21	May 25	July 21	May 25	July 21	May 25	July 21	May 25	July 21	May 25	July 21	May 25	July 21
0		.014	.009	.017	.009	.018	.010	.019	.010	.017	.010	.014	.004	.016	.008
		AMMONIUM NITRATE													
112		.014	.012	.019	.008	.022	.008	.019	.011	.019	.010	.012	.003	.017	.008
224		.016	.006	.014	.006	.015	.013	.032	.016	.019	.010	.014	.004	.018	.009
448		.018	.007	.023	.012	.016	.019	.026	.019	.021	.014	.010	.003	.019	.012
896		.039	.022	.063	.015	.080	.032	.090	.025	.068	.024	.012	.007	.057	.020
Avg		.022	.012	.030	.010	.033	.018	.042	.018	.032	.015	.012	.004	.028	.012
LSD .05															
Two grasses within a N rate = .007 ⁺⁺ (5/25); .010 ⁺⁺ (7/21)										--	--			--	--
N rates within a grass(es) = .030 ⁺⁺ (5/25); .012 ⁺⁺ (7/21)										.015	.006			.013	.005
		ANHYDROUS AMMONIA													
25	112	.013	.007	.016	.007	.020	.009	.016	.009	.016	.008	.019	.005	.017	.007
	224	.009	.012	.016	.007	.016	.012	.018	.006	.015	.009	.008	.013	.013	.010
	448	.011	.013	.044	.010	.045	.010	.060	.036	.040	.017	.009	.007	.034	.015
	896	.044	.037	.086	.032	.108	.043	.144	.089	.072	.050	.030	.006	.058	.041
	Avg	.019	.017	.041	.014	.047	.019	.060	.035	.036	.021	.017	.008	.031	.018

76	112	.012	.006	.016	.008	.019	.008	.015	.009	.016	.008	.011	.004	.015	.007
	224	.012	.006	.024	.010	.044	.009	.019	.008	.025	.008	.030	.005	.026	.008
	448	.047	.009	.065	.011	.058	.010	.116	.030	.072	.015	.032	.008	.064	.014
	896	.103	.034	.079	.023	.125	.083	.101	.088	.102	.057	.025	.015	.087	.049
	Avg	.044	.014	.046	.013	.062	.028	.063	.034	.054	.022	.025	.008	.048	.020
25 and 76	112	.013	.007	.016	.008	.020	.009	.016	.009	.016	.008	.015	.005	.016	.007
	224	.011	.009	.020	.009	.030	.011	.019	.007	.020	.009	.019	.009	.020	.009
	448	.029	.011	.055	.011	.052	.010	.088	.033	.056	.016	.021	.008	.049	.015
	896	.074	.036	.083	.028	.117	.063	.123	.089	.087	.054	.028	.011	.040	.045
LSD .05	Avg	.032	.016	.044	.014	.055	.023	.062	.035	.045	.022	.021	.008	.031	.019
Two grasses within a spacing and a N rate = .047 ⁺⁺															
(5/25); .025 ⁺⁺ (7/21)															
Spacings within a grass(es) and a N rate = .034 ⁺⁺															
(5/25); .015 ⁺⁺ (7/21)															
N rates within a spacing and a grass(es) = .043 ⁺⁺															
(5/25); .021 ⁺⁺ (7/21)															
51	896	.089	.029	.086	.031	.222	.007	.162	.088	.140	.039	.019	.010	.116	.033
102	896	.119	.098	.136	.088	.119	.108	.117	.149	.123	.088	.069	.052	.112	.081

⁺Three replications.

⁺⁺Value for comparing any two grasses on a sampling date.

were all below the critical level except on May 25 in tall fescue and reed canarygrass with 896 kg N as AA in 51-cm rows. These two determinations appear to be higher than expected compared with other AA spacings.

Anhydrous ammonia contributed to higher nitrate-N levels in grass foliage than AN in the second year. This indicated that more N was available in the second year from AA than AN because of greater N carry-over.

Grass samples taken May 25 from the low N treatments were similar to the checks (Table 10). Average level of nitrate-N accumulation was in the order of TF > RC > SB > OG > KB for both N sources. Orchardgrass nitrate-N levels were lower than tall fescue, reed canarygrass, and brome grass levels at high N rates because of slow regrowth and winter injury. Slow regrowth was possibly caused by low levels of carbohydrates under N fertilization as reported by Mitchell (1967) and Reynolds (1969). High second- and third-cutting yields in 1971 from orchardgrass had probably removed much of the soil nitrate-N. The low level of nitrate-N in orchardgrass at low N rates was similar to brome grass where soil nitrate-N was found to be very low.

By July 21, 1972, levels of nitrate-N were less than 0.09% on all grass treatments except at the 896-kg N rate as AA in 102-cm spacings. At this maximum rate and widest spacing, all grasses had high nitrate-N levels,

but were still below the potentially hazardous level. Apparently, no danger from high nitrate-N levels can be attributed to residual N in the second season at N rates up to 448 kg. By July 21, bluegrass had nitrate-N levels below 0.01% with all N rates as AN and with low rates of AA (Table 10). At the 896-kg rate as AA in 51-, 76-, and 102-cm rows, nitrate-N levels of 0.04 to 0.11% had accumulated.

The four deep-rooted grasses (Table 10) had higher nitrate-N accumulations than the shallow-rooted bluegrass with 896 kg N either as AN or as AA in 25-cm rows. A low percentage of nitrate-N in bluegrass indicated the applied N in the root zone (about 30 to 45 cm deep) had been utilized when fertilization was with AN. However, the high levels of nitrate-N in the foliage under 896 kg N as AA indicated N was still available to the bluegrass roots. This was indeed the case as will be discussed in the next section. Smooth brome grass, however, had a high level of plant nitrate-N accumulation which was associated with a high level of soil nitrate-N accumulation. Smith and Sund (1965) in Wisconsin reported brome grass contained large amounts of nitrate-N when the soil nitrate-N was high. In their study, brome grass grown in association with alfalfa had plant nitrate-N as high as 1.36%.

SECTION III

SOIL NITRATES

A. Literature Review

With high rates of nitrogen (N) on grass there is concern for surface and ground water contamination from soil nitrate-N not used by the grass. No data are available, however, indicating the movement of nitrate-N from anhydrous ammonia to depths below grass roots, while information is available on nitrate-N movement from ammonium nitrate. Larson, Carter, and Vasey (1971) in North Dakota reported no nitrate-N movement below 15 to 61 cm with 298 kg N/ha as ammonium nitrate applied annually for 15 years on brome grass (Bromus inermis Leyss.). The highest concentration 10 months after their fall application was at a soil depth of 30-46 cm. Power, et al. (1972) in North Dakota reported soil nitrate-N levels over four years were similar to the checks with a 110-kg rate of N. Furthermore, Ogus and Fox (1970) in Nebraska reported the deep brome grass roots were more effective on a per unit weight basis for nitrate-N uptake than the shallow roots.

Accumulations of nitrate-N under corn (Zea mays L.) increased yields of succeeding crops, but the content of nitrate-N in the soil is lower under a perennial grass stand than under corn. Lower concentrations of soil nitrate-N under timothy (Phleum pratense L.) than under corn were reported by Bizzell (1909) in New York. Increased soil nitrate-N content under corn was attributed to increased nitrification under cultivated soil. White, Dumenil, and Pesek (1958) in Iowa observed that the residual soil nitrogen one year after N application to corn was primarily in the form of nitrate-N in the 15- to 53-cm depth of soil. The N applications to corn did not significantly affect the level of exchangeable ammonium on the nitrification rate of soils the following spring. Yields of oats (Avena sativa L.) in 1953, however, were a linear function of N applied in 1952. Herron, et al. (1968) in Nebraska reported a high correlation between soil nitrate in the fall and corn yields without applied N the following year. They found most of the water or KCL extractable N in the surface 90 cm of a silt loam soil.

Grable and Johnson (1960) in Colorado reported that grass on a fine-textured soil recovered less applied N than on a coarse-textured soil. Linville and Smith (1971) in Missouri and Thomas (1970) concluded the slow leaching of nitrate under corn was influenced by a fine-textured soil. Low and high nitrate-N concentrations

have been associated with limited nitrification by McIntosh and Frederick (1958) in Iowa. Nitrification of 134 kg N/ha took 8 weeks on a sandy clay loam. The initial pH of 9.5 at the point of AA injection dropped to pH 5.5 after 4 weeks. Eno and Blue (1957) in Florida reported anhydrous ammonia increased the pH in a cylindrical 20-cm diameter area around the point of injection and optimum pH levels in the peripheral zone stimulated rapid nitrification. Nömmick and Nilsson (1963) in Sweden also reported high concentrations of ammonia inhibited nitrification and oxidation of nitrite to nitrate near the point of AA release. Frederick (1956) in Indiana reported nitrification of AA increased rapidly as temperature increased from 6 to 15 C, and 56 kg N/ha as AN on silt loam was nitrified in two months at an average temperature of 0 to 2 C. Cassel (1970) investigated leaching of nitrate-N and found that 896 kg N/ha as AN on fallow land irrigated with 26.7 cm of water caused a large accumulation of nitrate at a depth of 31 cm. After irrigation with 49.5 cm of water, most of the nitrate-N that accumulated at the depth of 31 cm was from nitrification of immobile ammonium. Stanley and Smith (1955) in Missouri reported ammonia retention in a silt loam was best at a soil moisture of 15 to 18%. They reported AA increased availability of P and K for a distance of 10 cm from the

point of injection. This distance corresponded to the distance of the pH effect.

With a more economical source of N from AA than from AN, greater rates of N on grass will be applied in one application. This investigation was undertaken to study the accumulation of soil nitrate-N from anhydrous ammonia applied at four rates of N in four row spacings to a deep- and a shallow-rooted grass.

B. Materials and Methods

The establishment and fertilization of stands of 'Lincoln' smooth brome grass (Bromus inermis Leyss.) and 'common' Kentucky bluegrass (Poa pratensis L.) on a Conover loam soil was described in Section I-B, Materials and methods. Average monthly air and soil temperatures and precipitation and irrigation added are also presented in Table 1 of Section I-B.

The grasses were fertilized (as described in Section I) with anhydrous ammonia (AA) on April 29, 1971, and with ammonium nitrate (AN) in split applications between May 7 and July 14, 1971.

Chemical and physical determinations made on April 29, 1971, in the upper 15 cm of the soil were as follows:

	<u>kg/ha</u>		
K	145	PH	6.5
P	105	CEC	4.8
Ca	1363	Bulk density	1.38
Mg	206	Base saturation	84%
Soluble salts	15	Soil moisture	12%

The soil temperature at a depth of 10 cm under grass was 10 C at 5 p.m. on April 29, 1971.

Samples for soil nitrate-nitrogen (nitrate-N) analyses were taken on both grasses in the summer and fall of both years. Samples were taken to a depth of at least 1.5 m on the following:

- A. At random on AN plots
- B. Over the 76-cm AA rows
- C. Midway between 76-cm AA rows.

N kg/ha	Sampling dates			
	July 12, 1971 ⁺	November 4, 1971 ⁺⁺	July 1, 1972 ⁺⁺	November 13, 1972 ⁺⁺
0	A	A	A	A
112	ABC	ABC	ABC	AB
224	ABC	ABC	ABC	AB
448	ABC	ABC	ABC	AB
896	-	AB ⁺⁺⁺	AB	AB

⁺Four replications.
⁺⁺Three replications.
⁺⁺⁺One replication on AN.

A Giddings Model GSR hydraulic soil-coring machine mounted on a tractor or a pick-up truck (Figure 16) was used to remove soil cores. A 5 x 152 cm soil core was taken from each 1.9 x 9.1 m grass plot. New areas of the plots were sampled on succeeding sampling dates.

Soil cores similar to the core shown in Figure 17 were divided into 15-cm increments and a 10-cm portion



Figure 16. Hydraulic soil-coring machine with a quick release bit on the end of a 11 x 152 cm soil tube.



Figure 17. Typical soil profile shown with 9 and 11 cm diameter soil tubes and a measuring trough used to divide the profile into 15-cm increments.

from the mid-section of each increment was taken as a sample. Samples were dried with forced air for 24 hours at 70 C, ground to pass a 2-mm sieve, and stored in paper bags until analysis.

The nitrate-N was determined on soil samples by the electrode method described by Bremner, Bundy, and Agarwal (1968) and was modified by use of a saturated calcium sulfate extracting solution. Fifty milliliters of extracting solution were added to 20 g. of soil and shaken for 30 minutes. Standards were prepared with KNO_3 . Constant stirring of the solution with a magnetic stirrer was necessary for accurate electrode readings. Results were converted from ppm nitrate-N to kg N/ha on the basis of 2.5 million kg soil in a 15-cm depth of soil in a hectare.

C. Results and Discussion

First Year (1971)

From the time of fertilizer application to July, 1971, soil nitrate-N had leached to a depth of 30 to 45 cm under both grasses at all rates as AA, and under the 448-kg N rate as AN (Figures 18a, 18b, 19a, and 19b, and Appendix Table 3). This "zone" of nitrate-N concentration under the AA rows and AN indicated only part of the N applied had been used by the grasses. Grass color, height, accumulation of plant nitrates, and yield increases discussed in Sections I and II also indicated the grasses

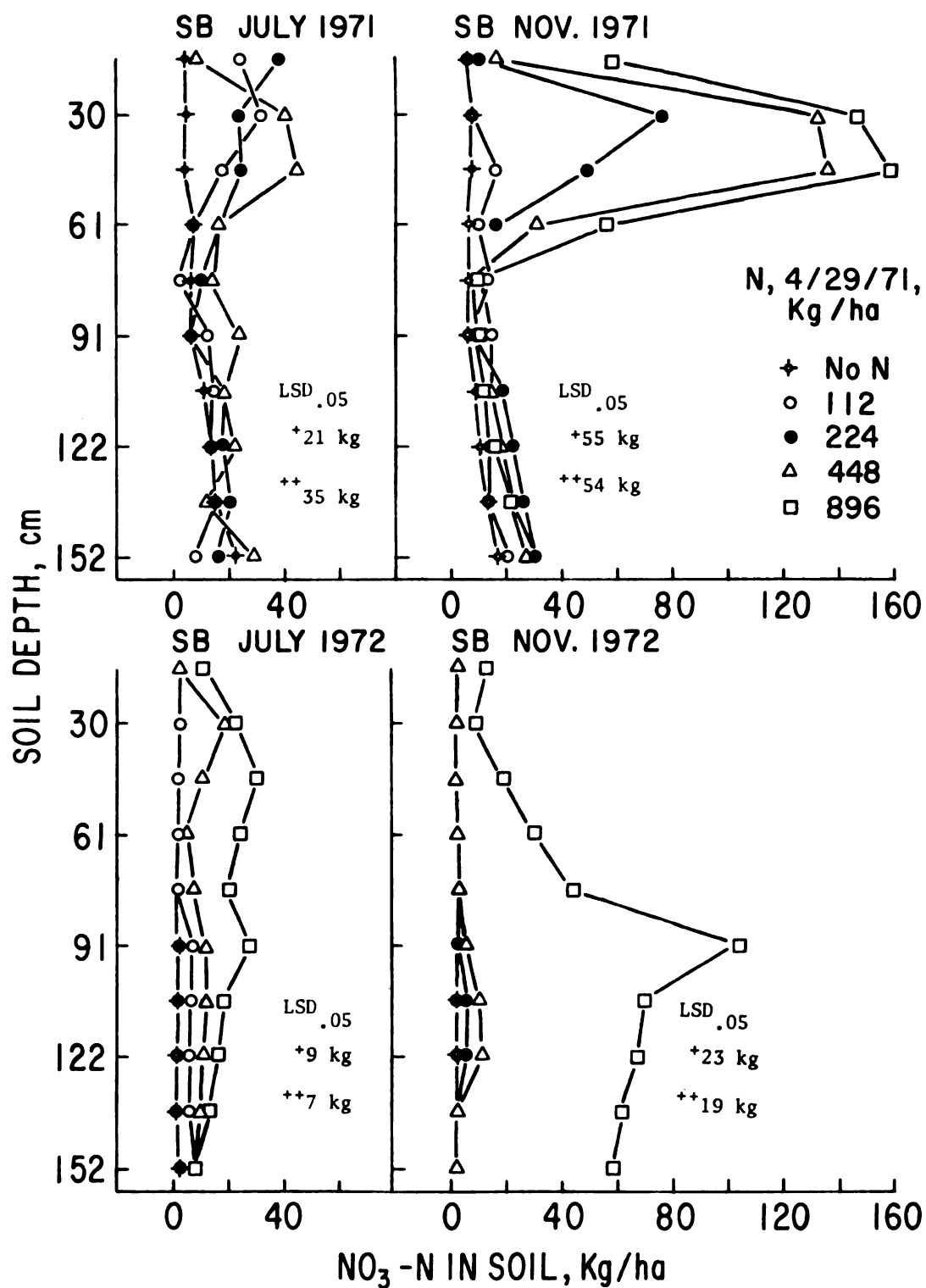


Figure 18a. Nitrate-N at 15-cm increments in Conover loam profiles measured in 1971 and 1972 under smooth bromegrass fertilized with N as AA on April 29, 1971.

+ N rate within a depth; ++ Depth within a N rate

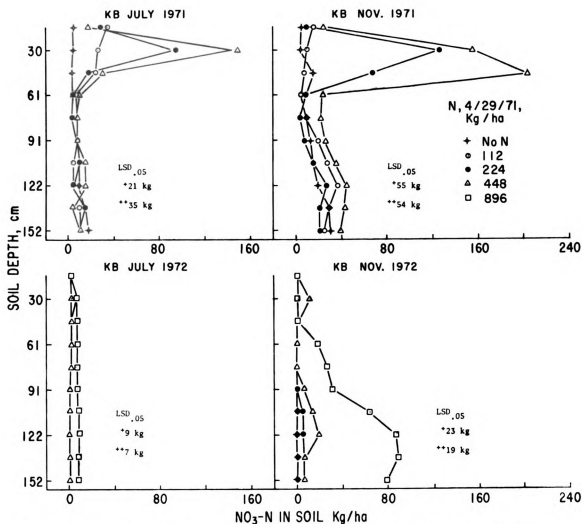


Figure 18b. Nitrate-N at 15-cm increments in Conover loam profiles measured in 1971 and 1972 under Kentucky bluegrass fertilized with N as AA on April 29, 1971. *N rate within a depth; **Depth within a N rate

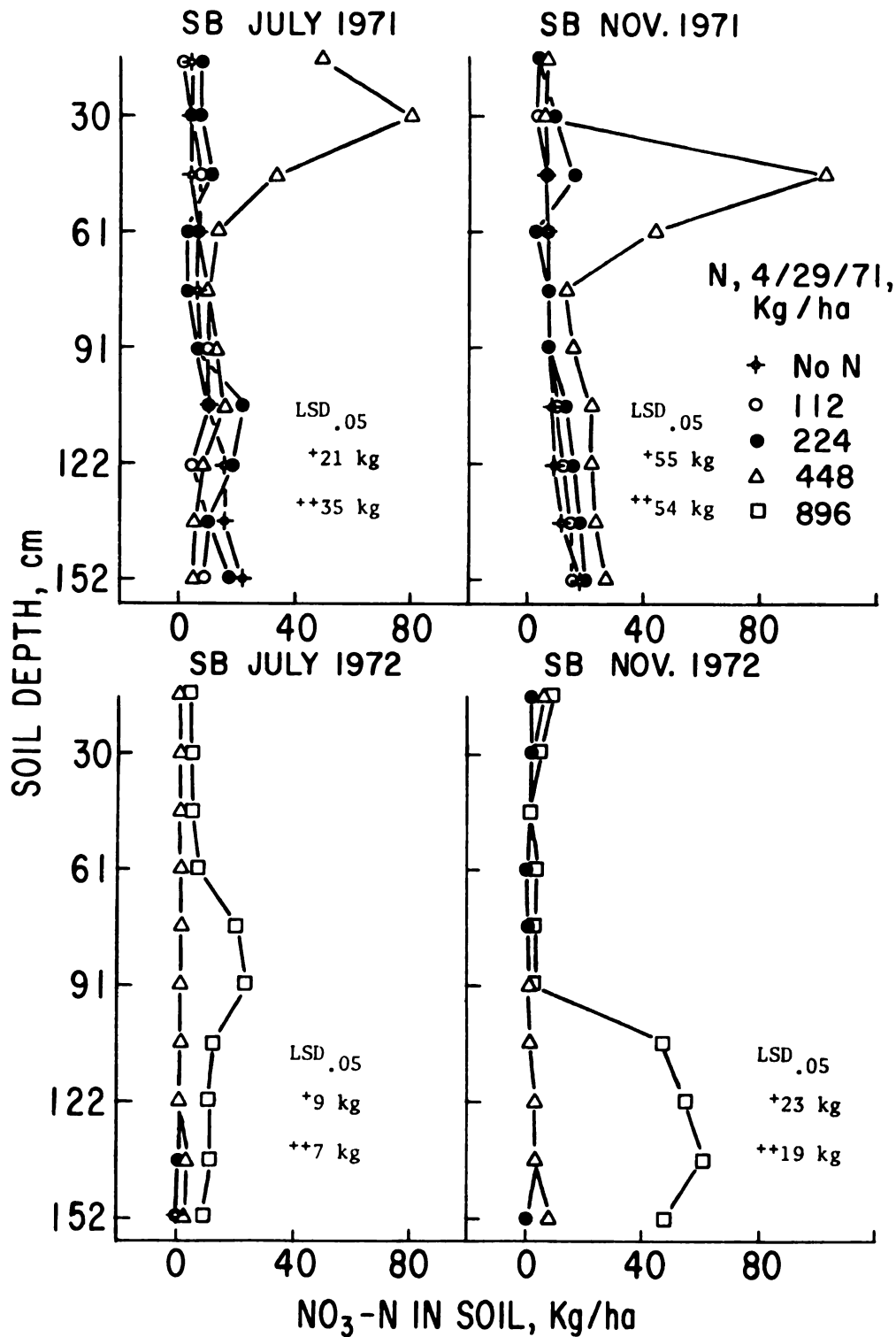


Figure 19a. Nitrate-N at 15-cm increments in Conover loam profiles measured in 1971 and 1972 under smooth brome grass fertilized with N as AN in split applications on May 7 and 26, June 16, July 9 and 14, 1971.

*N rate within a depth; **Depth within a N rate

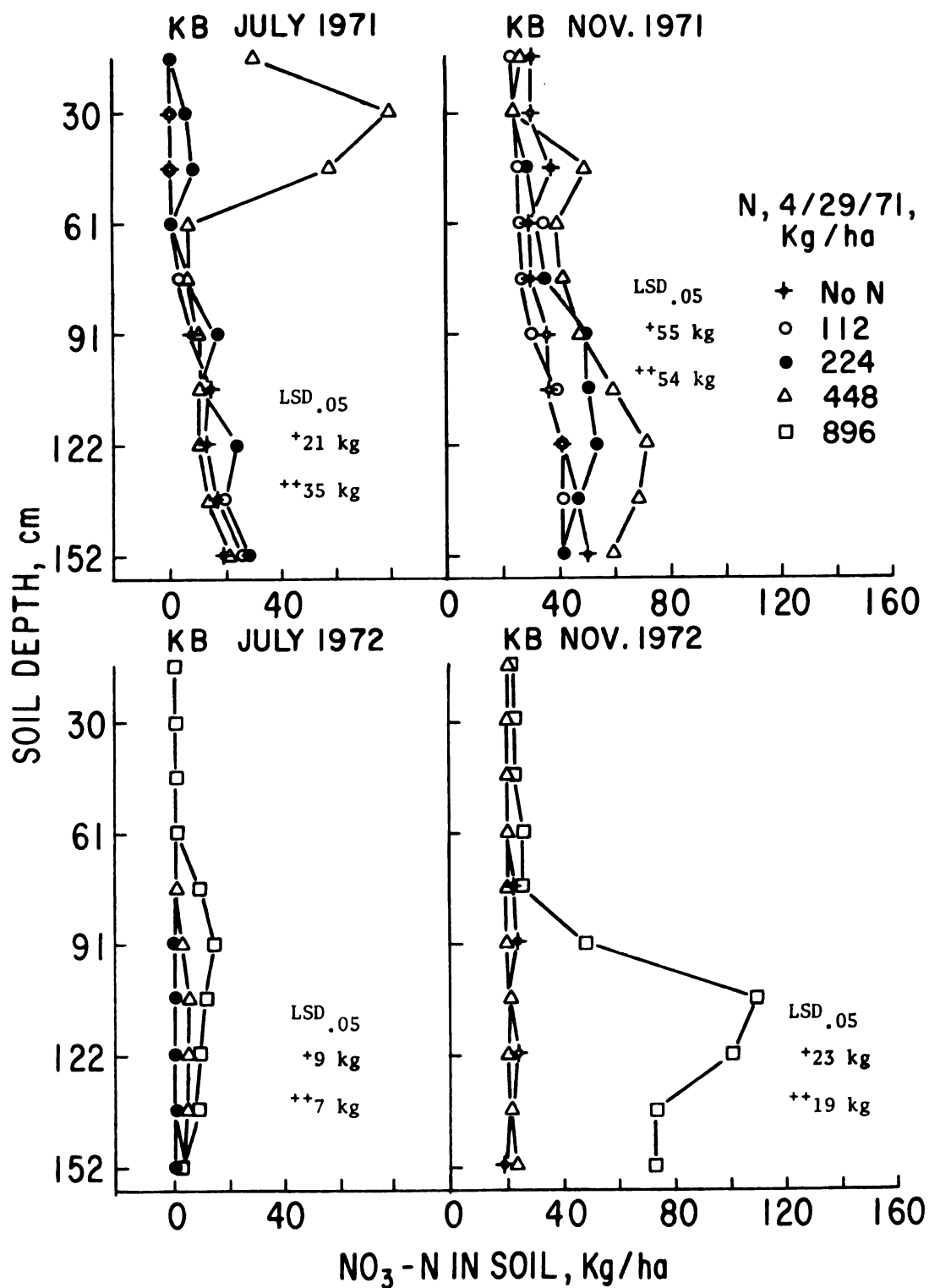


Figure 19b. Nitrate-N at 15-cm increments in Conover loam profiles measured in 1971 and 1972 under Kentucky bluegrass fertilized with N as AN in split applications on May 7 and 26, June 16, July 9 and 14, 1971.

*N rate within a depth; **Depth within a N rate

were getting N from both AA and AN. Greater grass yields with AN in the first cutting in June and lower accumulations of soil nitrate-N under AN than under AA indicated the grasses had used more nitrate-N from AN than from AA.

Smooth brome grass, a deep-rooted grass, removed twice the amount of nitrate-N from the AA source as Kentucky bluegrass, a shallow-rooted grass. This was because brome grass was higher yielding and because its roots penetrated deeper into the zone of available N under AA than roots of bluegrass.

Both grasses removed similar amounts of soil nitrate-N with low N rates as AN. With rates of N as AN above 224 kg, soil nitrate-N started to accumulate. This was because AN was broadcast and roots of bluegrass did not have to go as far to the AN as to the AA source of N. At rates above 224 kg, leaching occurred because the grasses could not readily use additional N.

Nitrate-N from all rates of N as AA and AN on grass remained in the upper 76 cm by November, 1971, except nitrate-N from the high rates of N as AN on bluegrass, which leached to a depth of 122 to 152 cm. A wetter soil under the shallow bluegrass roots may have enhanced nitrate-N leaching while the deep-rooted brome grass removed water and nitrates to a greater depth.

Soil nitrate-N content was higher under AA than under AN in the upper 76 cm of the soil profile six months

after AA application. Grasses fertilized with 224, 448, and 896 kg N as AA produced a lower yield and used less N in the first year than grasses fertilized with AN. At the two lowest rates of N as AN, the N had been used by the grasses by November but some nitrate-N still remained at the 30- to 45-cm depth under AA fertilization.

The highest accumulation of soil nitrate-N after six months was under bluegrass at the highest rate of N applied as AA. An accumulation of 265 kg N/ha of nitrate-N at a depth of 45 cm under bluegrass was the maximum concentration measured in 1971-1972 under any treatment. Bluegrass yielded less forage than brome grass and more of the nitrate-N remained in the soil after the season's growth.

Burn damage to foliage from AA was greater on bluegrass than on brome grass and probably contributed to less root absorption of nitrate-N and more leaching losses under bluegrass with high rates of AA. A 17-cm width of bluegrass foliage was killed with a rate of 896 kg N as AA. This 17-cm area had only partially recovered by November, 1971.

The loss by leaching of more nitrate-N from AN under bluegrass than under brome grass was evident in November, 1971. At the lowest rate of AN there was no accumulation of nitrate-N in the lower soil depths. but at 224 and 448 kg N as AN the nitrate increased under

bluegrass at the 91- to 137-cm depth. Apparently, bluegrass had not used the N in the root zone so more nitrate leached to the 91-cm depth under bluegrass than under bromegrass.

The accumulation of nitrate-N from July to November in the soil was greater from the AA than from the AN source of N. Both grasses used all the N at 112 and 224 kg N, whereas at 448 kg N there were significant leaching losses to the 122-cm depth under bluegrass. Soil nitrate-N losses to lower levels of the profile under 448 kg N as AN were associated with greater first-cut and usually greater second-cut yields of grasses with AN than with AA. At the third cutting in October, the grasses had higher yields with AA than with AN, and this corresponded to higher accumulations and greater availability of nitrate-N under ammonia-fertilized grasses. Yield and soil nitrate-N accumulation were positively correlated.

Soil nitrate-N accumulations measured midway between AA rows spaced 76-cm apart were similar to the checks in July, 1971, for all N rates, indicating that lateral spread of nitrogen from AA applied in rows was less than 38 cm (Appendix Table 4). By November, 1971, accumulations were similar to the check at the 112- and 224-kg rates, but were slightly greater than the check at the 448-kg rate of N as AA on bluegrass. At this higher N rate on bluegrass, the soil nitrate-N concentrations were greater

than the check throughout the area between the AA rows at a depth of 76 and 152 cm. This indicated the nitrate-N from the AA leached to this depth in the pattern of a triangle with the base downward. Samples from one replication taken to a depth of 180 cm at distances of 12, 26, and 38 cm from the AA row at a rate of 448 kg N also had increased accumulations of nitrate-N in a similar pattern.

Second Year (1972)

As sampling progressed from 1971 to 1972, the band of maximum nitrate-N accumulation moved downward under both grasses (Figures 18a, 18b, 19a, and 19b). Nitrate-N lost by leaching was usually greater under bluegrass than under brome grass. Total content of soil nitrate-N to a depth of 152 cm was less in 1972 than in 1971 (Appendix Table 3).

In 1972, nitrate-N content of the soil under both grasses was higher from AA than from AN in both the July and November samplings. The AA-fertilized soil had more nitrate-N in the root zone than soil fertilized with AN. This residual effect from AA on nitrate-N concentration corroborates the greater forage yield and higher percentage of nitrate-N in the grass foliage with AA than with AN in 1972, the year after N fertilization. Leaching losses of nitrate-N in 1972 were greater from AN than from AA because the grasses were unable to use all the nitrate-N from AN in the deeper depths.

By July, all of the N applied at rates of 112 and 224 kg/ha with both sources of N had been used by both grasses. At the 448-kg rate as AA, there was still nitrate-N available for both grasses in the surface 45 cm. With 448 kg N as AN all the nitrate-N had been used by brome-grass, but nitrate-N remained and leached to the 91- to 137-cm zone under bluegrass. Maximum soil nitrate-N concentration under AA-fertilized grass was at a shallower 30- to 61-cm depth than under AN which had nitrates leached to a greater depth of 61 to 122 cm.

Nitrate-N accumulated to a greater concentration in the soil profile between July and November under AA than under AN. The pattern of accumulation followed the same trend for both N sources.

By November 13, the 896-kg rate of N as AA had significantly higher concentrations of nitrate-N in the surface 76-cm of soil than a similar rate as AN. This indicated soil nitrate-N was still accumulating from the ammonia source of N in the surface 76 cm, while no nitrate-N was accumulating from the AN source of N. Under this high rate of N, nitrate-N concentrations were highest in the 76- to 107-cm depth with AA, but were highest at the lower depth of 91 to 137 cm under AN fertilization. Thus, the 896-kg rate of N as AA continued to supply nitrogen within the root zone of both grasses late in 1972 and this was reflected in yield responses in the third cutting in

1972. Ammonium nitrate was leached from the root zone of the short-rooted bluegrass which showed no yield response from nitrogen in the third cutting. Bromegrass, however, showed yield response at the highest N rate in the third cutting under AN and especially AA. The smooth bromegrass soil profile was drier than the bluegrass profile and nitrification may have been proceeding at a faster rate under bromegrass than under bluegrass in the 30-61 cm zone.

SUMMARY AND CONCLUSIONS

Shallow-rooted bluegrass and deep-rooted brome grass, reed canarygrass, orchardgrass, and tall fescue were established in 1970 on a Conover loam soil at East Lansing, Michigan. Nitrogen as anhydrous ammonia (AA) was injected 13-cm deep at rates of 112, 224, 448, and 896 kg/ha in 25-, 51-, 76-, and 102-cm rows on April 29, 1971. Similar rates of ammonium nitrate (AN) were broadcast in split applications from May 7 to July 14, 1971. The total effects of the N treatments were evaluated by combining the yields of three harvests in the first year and three harvests in the second year. Nitrate-N content of the foliage was determined in the first and second cuttings in 1971 and 1972. Soil nitrate-N levels under bluegrass and brome grass were determined in 15-cm increments to a depth of 152 cm in July and November of both years. The following conclusions are based on the results of this study.

I PRODUCTION

1. Grasses fertilized with AA consistently produced lower yields in the first cutting of the first year than when fertilized with AN, but higher yields were usually obtained with AA in the second and third cuttings in the first year.

2. First-year yields were greater at the 112-kg rate of N with AA, similar at the 224-kg rate from both N sources, and greater with AN at the two highest N rates.

3. Yields of grasses in the first year did not usually increase significantly as rates of N as AA exceeded 224 kg/ha.

4. In the second year, all grasses at all rates of AA yielded more than when fertilized with AN.

5. In the second year, yields increased as the row spacings of AA increased.

6. Grasses increased in total yields as N increased to the 896 kg rate.

7. The deep-rooted species fertilized with AA yielded 5, 12, 5, and 2% more total forage at the 112-, 224-, 448-, and 896-kg/ha rates of N, respectively, than when fertilized with AN.

8. Grasses yielded in the order bromegrass > tall fescue > reed canarygrass > orchardgrass > bluegrass.

9. Row spacings of AA from 25 to 102 cm had no effect on total two-year yields of the deep-rooted grasses.

10. Bluegrass yielded less at the two widest spacings of AA at all rates of A except at the lowest rate of 112 kg/ha.

11. Percentage of stimulation by N of the grasses between 102-cm rows of AA at the 224-kg N rate by the third cutting in the first year were: OG (84), SB (83), RC (76),

TF (74), and KB (66). As the N rate increased to 448 and 896 kg/ha or row spacings decreased to 51 and 25 cm, grasses were stimulated on 100% of the area.

II PLANT NITRATES

1. Orchardgrass had the highest concentrations of nitrate-N, whereas tall fescue, reed canarygrass, and bromegrass had similar intermediate concentrations. Bluegrass always had lowest concentrations.

2. Levels of nitrate-N in each grass species were similar as row spacing of AA increased from 25 to 76 cm.

3. By June 10, six weeks after initial fertilization, higher plant nitrate-N concentrations were found in grasses fertilized with AA than with AN at N rates of 224 kg, but at the 448-kg rate of N, grasses fertilized with AN had higher nitrate-N concentrations. Orchardgrass at the 112- and 224-kg rates of N had 0.135 and 0.191% nitrate-N, respectively, twice that of the other deep-rooted grasses.

4. By July 23, twelve weeks after fertilization, nitrate-N levels were higher in all grasses with AA at 112 and 224 kg N, equal at the 448-kg N rate, but higher with AN at the 896-kg N rate. At the 112-kg rate of N as AA all grasses were below 0.15% nitrate-N (accepted "safe" for livestock), but only bluegrass and reed canarygrass were "safe" at 224 kg N/ha.

5. Grasses, especially orchardgrass, increased in nitrate-N from June 10 to July 23 of the first year with greatest increases with highest amounts of applied N.

6. On both sampling dates of the first year, all grasses except tall fescue fertilized with 112 and 224 kg N as AN had less than 0.15% nitrate-N. Grasses fertilized with 112 kg N as AN had levels of nitrate-N similar to the check by July 23.

7. Grass fertilized with AA had higher nitrate-N levels than from AN in the second year.

8. Percentages of nitrate-N were generally well below the safe nitrate-N level for all grasses on May 25 of the second year, and remained low on July 21.

9. Levels of nitrate-N in orchardgrass were lower than in the other deep-rooted grasses in the second year.

III SOIL NITRATES

1. The deep-rooted bromegrass removed more total soil nitrate-N from the upper 76 cm of the soil profile than the shallow-rooted bluegrass.

2. Three months after N application, nitrate-N had leached to a depth of 30 to 45 cm under AA and AN.

3. From July to November of the first year, the accumulation of nitrate-N was greater from AA than from the AN source of N.

4. At the 112- and 224-rates of N as AN, the N had been used by the grasses by November of the first year, but there was still nitrate-N at the 30- to 45-cm depth under AA fertilization.

5. In the first year at rates of 448 and 896 kg/ha of N, leaching below the root depth occurred because the additional N was not used by the grasses.

6. Nitrate-N from all rates of N remained in the upper 76 cm of the soil in November of the first year with the exception of the high rates of AN on bluegrass where nitrate-N leached to a depth of 122 to 152 cm.

7. In the second year, the nitrate-N content of the soil under both grasses was higher from AA than AN.

8. Total nitrate-N content of the soil to a depth of 152 cm was lower in the second than in the first year.

9. Soil nitrate-N moved downward in the soil profile in a band under rates of 448 and 896 kg N/ha and accumulated at depths of 96 to 137 cm under AN, and 76 to 107 cm under AA at the end of the second year, 18 months after fertilization with N. This nitrate-N was at or exceeded the depth of 122 cm, determined as the maximum root depth of brome grass. This nitrate-N could contribute to ground water contamination.

10. Eighteen months after N fertilization, the soil nitrate-N was still accumulating from the AA source of N in the surface 76 cm while no nitrate-N was accumulating from the AN source of N.

Anhydrous ammonia is as effective as AN for increasing two-year total yields of grass, because more residual soil nitrate-N is available for grass use in the second season from AA than from AN. A rate of 224 kg N/ha as AA is a desirable rate because in the first season grass yields are near optimum, safe levels of nitrate-N in the foliage are maintained, and levels of nitrate-N in the soil that could potentially contaminate ground water do not accumulate. Leaching losses of the soil nitrate-N are less with AA than AN at 448 kg N/ha under the shallow-rooted bluegrass, while the deep-rooted brome grass at 448 kg N as AA removes more nitrate-N and significant levels of soil nitrate-N do not accumulate after two seasons. The 896 kg N rate with AA and AN significantly increased levels of nitrate-N in the soil, and could contaminate ground water.

LITERATURE CITED

LITERATURE CITED

- Andrews, W. B. 1956. Anhydrous ammonia as a nitrogenous fertilizer. *Advances in Agron.* 8:61-125.
- Andrews, W. B., J. A. Neely, and F. E. Edwards. 1951. Anhydrous ammonia as a source of nitrogen. *Mississippi Agr. Exp. Sta. Bull.* 482. 39 p.
- apGriffith, G. 1960. The nitrate nitrogen content of herbage. I. Observations on some herbage species. *J. Sci. Food Agr.* 11:622-626.
- Bizzell, J. A. 1909. Some conditions affecting nitrification in Dunkirk clay loam. *Proc. Amer. Soc. Agron.* 1:222-227.
- Bremner, J. M., L. G. Bundy, and A. S. Agarwal. 1968. Use of a selective ion electrode for determination of nitrate in soils. *Anal. Letters.* 1:837-844.
- Burton, G. W., and J. E. Jackson. 1962. Effect of rate and frequency of applying six nitrogen sources on coastal bermudagrass. *Agron. J.* 54:40-43.
- Cassel, D. K. 1970. Solute movement in soils: I. Leaching of nitrate in irrigated fallow soil. *North Dakota Farm Res.* 28:15-17.
- Cowling, D. W. 1968. Ammonia as a source of nitrogen for grass swards. *J. Brit. Grassland Soc.* 23:53-60.
- Crawford, R. F., W. K. Kennedy, and M. J. Wright. 1960. Nitrate in forage crops and silage-benefits, hazards, and precautions. *Cornell Univ. Misc. Bull.* 37. 15 p.
- Crawford, R. F., W. F. Kennedy, and W. C. Johnson. 1961. Some factors that affect nitrate accumulation in forages. *Agron. J.* 53:159-162.
- Dotzenko, A. D., and K. E. Henderson. 1964. Performance of five orchardgrass varieties under different nitrogen treatments. *Agron. J.* 56:152-5.

- Drysdale, A. D. 1970. Anhydrous ammonia as a grassland fertilizer. XI Int. Grassland Cong. Proc. (Surfer's Paradise, Australia), April 13-23, pp. 424-427.
- Eno, C. F., and W. G. Blue. 1957. The comparative rate of nitrification of anhydrous ammonia, urea, and ammonium sulfate in sandy soils. Soil Sci. Soc. Amer. Proc. 21:392-396.
- Frederick, L. R. 1956. The formation of nitrate from ammonium nitrogen in soils: I. Effect of temperature. Soil Sci. Soc. Amer. Proc. 20:496-500.
- George, J. R., C. L. Rhykerd, G. O. Mott, R. F. Barnes, and C. H. Noller. 1972. Effect of nitrogen fertilization of Festuca arundinacea Schreb. on nitrate nitrogen and protein content and the performance of grazing steers. Agron. J. 64:24-26.
- Grable, A. R., and D. D. Johnson. 1960. Efficiency of recovery of applied nitrate nitrogen by perennial ryegrass from different soils. Soil Sci. Soc. Am. Proc. 24:503-507.
- Hansen, C. M., M. B. Tesar, and L. S. Robertson. 1970. Anhydrous ammonia sod knife applicator design. Anhydrous ammonia symposium, National College of Agri. Eng., SILSOE, Bedford, U. K.
- Herron, G. M., G. L. Terman, A. F. Dreier, and R. A. Olson. 1968. Residual nitrate nitrogen in fertilized deep loess-derived soils. Agron. J. 60:447-481.
- Hill, R. M., and C. W. Ackerson. 1964. Nitrate in cattle feeds can be deadly. Nebraska Agr. Exp. Sta. Quart. Summer, p. 3-5.
- Hill, W. E., and B. B. Tucker. 1968. A comparison of injected anhydrous ammonia into bermudagrass sod compared to topdressed applications of urea and ammonium nitrate. Soil Sci. Soc. Amer. Proc. 32:257-261.
- Hojjati, S. M., T. H. Taylor, and W. C. Templeton, Jr. 1972. Nitrate accumulation in rye, tall fescue, and bermudagrass as affected by nitrogen fertilization. Agron. J. 64:624-627.

- Jeater, R. S. L. 1967. Comparisons of liquified (anhydrous) ammonia and ammonium nitrate as nitrogenous fertilizers for grassland. J. Brit. Grassland Soc. 22: 225-229.
- Kennedy, W. K. 1960. Nitrogen fertilization on meadows and pastures. Bull. 935. Cornell Univ. Agr. Exp. Sta. N.Y. State Coll. of Agr., Ithaca, N. Y.
- Larson, K. L., J. F. Carter, and E. H. Vasey. 1971. Nitrate-nitrogen accumulation under brome grass sod fertilized annually at six levels of nitrogen for fifteen years. Agron. J. 63:527-528.
- Lechtenberg, V. L., H. J. King, G. O. Mott, and D. A. Huber. 1970. Effect of anhydrous ammonia on the composition and yield of Bromus inermis and Dactylis glomerata. Agron. Abstr., Ann. Meetings, Amer. Soc. Agron. Aug. 23-27. Tucson, Ariz., p. 76.
- Linville, K. W., and G. E. Smith. 1971. Nitrate content of soil cores from corn plots after repeated nitrogen fertilization. Soil Sci. 112:249-255.
- Look Kin, W. K., and A. F. MacKenzie. 1970. Effect of time and rate of N applications on yield, nutritive value index, crude protein, and nitrate content of brome grass. Agron. J. 62:443-444.
- Lucey, R. F. 1959. Effects of frequency and rate of irrigation, fertilization, and clipping treatments on yield and botanical composition of several forage species. Ph.D. Thesis, Michigan State Univ. (Libr. Congr. Card No. Mich. 61-1145).
- McIntosh, T. H., and L. R. Frederick. 1958. Distribution and nitrification of anhydrous ammonia in a nicollet sandy clay loam. Soil Sci. Soc. Amer. Proc. 22: 402-405.
- McVicker, M. H., W. P. Martin, I. E. Miles, and H. H. Tucker. 1966. Agricultural anhydrous ammonia. Amer. Soc. Agron., Madison, Wis., 314 p.
- Madison, J. H. 1972. Nitrate critical range studies of blue, bent, and Bermuda turfgrasses using the nitrate electrode. Agron. Abstr., 1972. Ann. Meetings, Amer. Soc. Agron. Oct. 29-Nov. 2, Miami Beach, Fla., p. 64.

- Mitchell, W. H. 1967. Influence of cutting heights, irrigation and nitrogen on the growth and persistence of orchardgrass. Agr. Exp. Sta., Univ. of Delaware Bull. 364, 15 p.
- Murphy, L. S., and G. E. Smith. 1967. Nitrate accumulations in forage crops. Agron. J. 59:171-174.
- Nömmik, H., and K. O. Nilsson. 1963. Nitrification and movement of anhydrous ammonia in soil. Acta Agr. Scand. 13:205-219.
- Ogus, L., and R. L. Fox. 1970. Nitrogen recovery from a soil profile by Bromus inermis. Agron. J. 62:69-71.
- Paul, J. L., and R. M. Carlson. 1968. Nitrate determination in plant extracts by the nitrate electrode. J. Agr. Food Chem. 16:766-768.
- Power, J. F., J. Aless, G. A. Reichman, and D. L. Grunes. 1972. Effect of nitrogen source on corn and bromegrass production, soil pH, and inorganic soil nitrogen. Agron. J. 64:341-344.
- Ramage, C. H., C. Eby, R. E. Mather, and E. R. Purvis. 1958. Yield and chemical composition of grasses fertilized heavily with nitrogen. Agron. J. 50:59-62.
- Reynolds, J. H. 1969. Carbohydrate reserve trends in orchardgrass (Dactylis glomerata L.) grown under different cutting frequencies and nitrogen fertilization levels. Crop Sci. 9:720-723.
- Reynolds, J. H., C. R. Lewis, and K. F. Laaker. 1971. Chemical composition and yield of Orchardgrass forage grown under high rates of nitrogen fertilization and several cutting management. Tennessee Agr. Exp. Sta. Bull. 479, 27 p.
- Ryan, M., W. F. Wedin, and W. B. Bryan. 1972. Nitrate-N levels of perennial grasses as affected by time and level of nitrogen application. Agron. J. 64:165-168.
- Smith, D., and J. M. Sund. 1965. Influence of stage of growth and soil nitrogen nitrate content of herbage of alfalfa, red clover, ladino clover, trefoil, and bromegrass. J. Agr. Food Chem. 13:81-84.
- Smith, G. E. 1970. The nitrate panic button--what are the facts? Michigan Fertilizer Conf. Proc., East Lansing, Michigan.

- Stanley, F. A., and G. E. Smith. 1955. Proper application improves value of NH_3 . Agr. Ammonia News April-June Tech. Bull. AA-8, 4 p.
- Stewart, B. A. 1970. A look at agricultural practices in relation to nitrate accumulation. p. 47-60. In O. P. Engelstad (ed.) Nutrient mobility in soils: Accumulation and losses. Special Publ. No. 4, Soil Sci. Soc. Amer., Madison, Wis. 81 p.
- Tesar, M. D., C. M. Hansen, and L. S. Robertson. 1971. Anhydrous ammonia fertilization of grasses. Agron. Abstr. Ann. Meetings, Amer. Soc. Agron. Aug. 15-20, New York, N. Y., p. 39.
- Tesar, M. D., C. M. Hansen, and L. S. Robertson. 1972. Increasing grass yields with anhydrous ammonia (Progress report). Michigan Agr. Exp. Sta. Res. Rep. 166, pp. 99-102.
- Thomas, G. A. 1970. Soil and climatic factors which affect nutrient mobility. p. 20. In O. P. Engelstad (ed.) Nutrient mobility in soils: Accumulation and losses. Special Publ. No. 4. Soil Sci. Soc. Amer., Madison, Wis. 81 p.
- U.S. Department of Agriculture. 1970. Agricultural Prices, SRS, April 15, 1970.
- Van Burg, P. F. J., G. D. Van Brakel, and J. H. Schepers. 1967a. The agricultural value of anhydrous ammonia on grassland: experiments (1963-1965). Netherlands Nitrogen Tech. Bull. No. 2. March, 1967, 31 p.
- Van Burg, P. F. J., G. D. Van Brakel, and J. H. Schepers. 1967b. The agricultural value of anhydrous ammonia on arable land: experiments (1963-1966). Netherlands Nitrogen Tech. Bull. No. 3, May, 1967, 39 p.
- Wagner, R. E. 1954. Legume nitrogen versus fertilizer nitrogen in protein production of forage. Agron. J. 46:233-237.
- Washko, J. B., and L. F. Marriott. 1960. Yield and nutritive value of grass herbage as influenced by nitrogen fertilization in the Northeastern United States. VIII Int. Grassland Cong. Proc. (Reading, U. K.), July 11-21, pp. 137-141.

White, W. C., L. Dumenil, and J. Pesek. 1958. Evaluation of residual nitrogen in soils. Agron. J. 50:255-259.

Wright, M. J., and K. L. Davison. 1964. Nitrate accumulation in crops and nitrate poisoning in animals. Advance Agron. 16:197-247.

APPENDIX

Appendix Table 1. Average stimulation of grasses by N, in percentage, rated visually at each harvest in two years by color and height of grasses between four row spacings of AA applied at four rates of N on April 29, 1971.

Spacing, cm	N Rate, kg/ha	Smooth brome ⁺ grass				Reed canarygrass ⁺				Orchard- grass ⁺				Tall fescue ⁺				Kentucky bluegrass ⁺				Avg SB, RC, OG, TF			
		1971		1972		1971		1972		1971		1972		1971		1972		1971		1972		1971		1972	
		1971	1972	1971	1972	1971	1972	1971	1972	1971	1972	1971	1972	1971	1972	1971	1972	1971	1972	1971	1972	1971	1972		
25	112	100	12	100	17	100	9	99	16	97	9	100	14												
	224	100	35	100	23	100	10	100	30	100	27	100	25												
	448	100	86	100	79	100	70	100	83	100	72	100	80												
	896	100	100	100	100	100	94	100	100	100	93	100	99												
	Avg	100	58	100	55	100	46	100	57	99	50	100	55												
51	112	94	12	75	10	88	9	86	9	78	9	86	10												
	224	98	40	89	37	92	13	92	40	90	36	93	33												
	448	99	80	93	75	98	68	99	82	92	63	97	76												
	896	100	99	99	99	100	93	100	100	98	88	100	98												
	Avg	98	58	89	55	95	46	94	58	90	49	94	54												
76	112	76	9	62	13	72	13	66	18	52	13	69	13												
	224	79	41	75	36	80	27	70	40	63	29	76	36												
	448	86	73	85	70	87	66	83	83	78	38	85	73												

896	95	95	89	98	90	89	86	100	89	77	90	96
Avg	84	55	78	54	82	49	76	60	71	39	80	55
102	112	60	17	54	13	60	10	54	16	44	15	14
	224	70	46	63	34	68	14	62	38	56	26	33
	448	78	82	70	72	80	73	71	62	67	49	72
	896	90	96	84	92	83	82	81	92	78	70	91
Avg	75	60	68	53	73	73	45	67	52	61	40	53
A11	112	83	13	73	13	80	10	76	15	68	12	13
	224	87	41	82	33	85	16	81	37	77	30	32
	448	91	80	87	74	91	69	88	78	84	56	75
	896	96	98	93	97	93	90	92	98	91	82	96
Avg	89	58	84	84	54	87	46	84	57	80	45	54

⁺ Average of three cuttings each year from four replications.

Appendix Table 2. Average⁺ stimulation of grasses by N, in percentage, rated visually October 20, 1971, by color and height of grass between four row spacings of AA applied at four rates of N on April 29, 1971.

Spacing, cm	N Rate, kg/ha	Smooth bromegrass	Tall fescue	Orchard grass	Reed canarygrass	Kentucky bluegrass	Avg SB,TF,OG,RC	Avg All
25	112	100	100	100	100	100	100	100
	224	100	100	100	100	100	100	100
	448	100	100	100	100	100	100	100
	896	100	100	100	100	100	100	100
	Avg	100	100	100	100	100	100	100
51	112	100	80	95	95	95	93	93
	224	100	100	100	100	100	100	100
	448	100	100	100	100	100	100	100
	896	100	100	100	100	100	100	100
	Avg	100	95	99	99	99	98	98
76	112	93	66	86	88	58	83	78
	224	88	80	93	79	71	85	82
	448	100	100	100	100	98	100	100

	896	100	100	100	100	100	100	100	100	100
	Avg	95	87	95	92	82	92	90		
102	112	69	66	68	71	55	69	66		
	224	83	74	84	76	66	79	77		
	448	95	85	98	91	81	92	90		
	896	100	100	100	98	100	100	100		
	Avg	87	81	88	84	76	85	83		
Avg, All	112	91	78	87	89	77	86	84		
	224	93	89	94	89	84	91	90		92
	448	99	96	100	98	95	98	98		
	896	100	100	100	100	100	100	100		
	Avg	96	91	95	94	89	94	93		

⁺Four replications

Appendix Table 3. Amounts of nitrate-N in kg/ha, determined under 76-cm rows of AA and under AN broadcast on a Conover loam at East Lansing, Michigan. Fertilizer N as AA was applied 13-cm deep on April 29, 1971, and AN was applied in split applications on May 7 and 26, June 16, July 9 and 14, 1971.

N applied, kg/ha												
112				224				448				896
Depth, cm	1971		1972		1971		1972		1971		1972	
	July	Nov	July	Nov	July	Nov	July	Nov	July	Nov	July	Nov
ANHYDROUS AMMONIA ON SMOOTH BROMEGRASS												
0- 15	25	7	2	2	38	9	2	2	9	18	2	2
15- 30	31	7	2	2	25	76	2	2	40	132	18	2
30- 46	18	16	2	2	25	49	2	2	45	136	9	2
46- 61	7	9	2	2	16	16	2	2	16	34	4	2
61- 76	2	13	2	2	9	11	2	2	11	11	7	2
76- 91	11	7	2	2	7	11	7	2	25	13	9	4
91-107	13	11	2	2	18	18	4	4	18	16	9	9
107-122	16	13	2	2	18	22	4	4	22	18	7	11
122-137	18	13	2	2	20	27	4	2	13	22	7	2
137-152	9	20	2	2	16	29	7	2	29	27	7	2
Total	150	116	20	20	192	268	36	24	228	427	79	38

AMMONIUM NITRATE ON SMOOTH BROMEGRASS

0- 15	2	7	2	2	7	4	2	2	49	7	2	7	16	2	9
15- 30	4	4	2	2	7	9	2	2	81	7	2	2	204	2	4
30- 46	7	16	2	2	9	7	2	2	34	103	2	2	150	4	2
46- 61	7	7	2	2	4	4	2	2	13	43	2	4	13	9	2
61- 76	9	7	2	2	4	7	2	2	9	13	2	4	16	22	2
76- 91	9	7	2	2	7	7	2	2	13	16	2	4	20	25	4
91-107	11	11	2	2	22	13	2	2	16	22	2	2	22	13	47
107-122	5	13	2	2	18	16	2	2	8	22	2	4	27	11	56
122-137	11	16	2	2	11	18	2	2	7	25	4	4	29	11	61
137-152	8	16	2	2	20	20	4	2	6	27	4	9	31	9	49
Total	75	104	20	20	109	105	22	20	236	285	24	42	528	108	236

Appendix Table 3.--Continued.

N applied, kg/ha																		
Depth, cm	112						224						448				896	
	1971		1972		1971		1972		1971		1972		1971		1972		Nov ⁺	July Nov
	July	Nov	July	Nov	July	Nov	July	Nov	July	Nov	July	Nov	July	Nov	July	Nov		
	Nov	Nov	Nov	Nov	Nov	Nov	Nov	Nov	Nov	Nov	Nov	Nov	Nov	Nov	Nov	Nov		
ANHYDROUS AMMONIA ON KENTUCKY BLUEGRASS																		
0- 15	36	16	2	2	29	13	2	4	20	27	2	2	34	2	4			
15- 30	31	13	2	2	94	130	2	4	150	157	9	13	155	11	2			
30- 46	25	9	2	2	22	66	2	2	31	206	4	2	265	7	4			
46- 61	9	9	2	2	2	11	2	2	13	22	4	2	54	7	20			
61- 76	9	11	2	2	4	9	2	2	9	22	9	2	20	11	31			
76- 91	9	22	2	2	7	13	4	2	9	29	11	7	13	13	36			
91-107	9	29	2	2	16	18	4	7	18	36	13	16	25	13	67			
107-122	9	38	2	2	11	25	4	7	18	45	13	22	36	13	90			
122-137	16	29	2	2	18	22	4	7	13	43	11	16	31	11	90			
137-152	16	27	2	2	16	20	4	9	16	40	9	11	29	11	83			
Total	169	203	20	20	219	327	30	46	297	627	85	93	662	99	427			

ANHYDROUS AMMONIA ON KENTUCKY BLUEGRASS

AMMONIUM NITRATE ON KENTUCKY BLUEGRASS

0- 15	2	4	2	2	2	7	2	2	31	7	2	2	40	2	4
15- 30	2	4	2	2	7	4	2	2	81	4	2	2	359	2	4
30- 46	2	7	2	2	9	9	2	2	58	31	2	2	209	2	4
46- 61	2	7	2	2	2	9	2	2	7	20	2	2	85	2	7
61- 76	4	7	2	2	7	16	2	2	7	22	2	2	43	11	7
76- 91	11	11	2	2	18	31	2	2	11	29	4	2	45	16	29
91-107	16	18	2	2	13	31	2	2	13	40	7	2	43	13	90
107-122	13	22	2	2	25	34	2	2	11	52	7	2	40	11	81
122-137	18	22	2	2	20	27	2	2	16	49	7	2	40	9	54
137-152	27	22	4	2	29	22	2	2	22	40	4	4	40	4	54
Total	97	124	22	20	132	190	20	20	257	294	39	22	944	72	324

⁺One replication of ammonium nitrate.

Appendix Table 4. Amounts of nitrate-N in kg/ha, determined under a point midway between 76-cm rows of AA applied 13-cm deep on April 29, 1971, on a Conover loam at East Lansing, Michigan.

Depth, cm	Check						N applied, kg/ha					
	1971			1972			112			224		
	July	Nov	July	Nov	July	Nov	July	Nov	July	Nov	July	Nov
	4	7	2	2	2	4	7	2	2	9	2	11
0- 15	4	7	2	2	2	4	7	2	2	9	2	11
15- 30	4	7	2	2	2	2	7	2	2	8	2	7
30- 46	4	7	2	2	2	4	7	2	2	8	2	16
46- 61	7	7	2	2	2	4	7	2	2	7	2	9
61- 76	7	7	2	2	2	4	7	2	2	9	2	7
76- 91	7	7	2	4	4	2	7	2	2	9	2	7
91-107	11	9	2	2	2	9	9	2	2	9	2	11
107-122	16	11	2	2	2	18	13	2	2	9	4	16
122-137	16	13	2	2	2	16	18	2	2	16	7	25
137-152	22	18	2	2	2	25	20	2	2	22	4	34
Total	98	93	20	20	20	88	112	20	20	43	106	52
												143
												29

ANHYDROUS AMMONIA ON SMOOTH BROMEGRASS

ANHYDROUS AMMONIA ON KENTUCKY BLUEGRASS

0- 15	2	11	2	2	2	2	7	2	2	9	2	2	7	2
15- 30	2	11	2	2	2	2	4	2	2	7	2	2	4	9
30- 46	2	18	2	2	2	2	4	2	2	9	2	2	4	4
46- 61	2	11	2	2	2	2	7	2	2	4	2	2	9	4
61- 76	4	11	2	4	2	2	7	2	13	11	2	7	16	9
76- 91	9	16	2	4	7	11	11	2	18	16	4	11	29	11
91-107	16	17	2	2	16	16	16	2	11	25	4	16	40	13
107-122	13	22	2	4	13	22	22	2	25	34	4	13	52	13
122-137	18	27	2	2	9	22	22	2	20	29	4	16	54	11
137-152	20	31	2	2	13	22	22	2	16	27	4	16	58	9
Total	86	175	20	26	68	122	122	20	113	174	30	87	273	85

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