EFFECT OF NITROGEN AND SULFUR ON YIELD,
NUTRIENT UPTAKE, AND N/S RATIOS
IN BERMUDAGRASS

By

CARL EUGENE WOODS, JR.

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Thesis Approved:

Robert L. Westerman
Thesis Adviser

R. E. McMurphy

Gordon V. Johnson

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Crop deficiencies of plant nutrient sulfur have been appearing in most parts of the world with increasing frequency in recent years. Contributing factors have been continued high crop production, widespread use of higher analysis sulfur-free fertilizers, and decreased atmospheric sulfur dioxide levels due to environmental control measures.

Sulfur deficiency in plants and soil is difficult to predict. However, nitrogen/sulfur ratios in crops and forages have been used as a guide to predict S needs and response from fertilization, but critical ratios vary for different crop species and within the same species grown under different environments. Soil tests for S that predict S fertilizer requirements have been employed but need to be refined for forage production.

The objectives of this study were to determine the effects of N and S fertilization on dry matter yield, nutrient concentration, nutrient uptake, and N/S ratio in bermudagrass (Cynodon dactylon L. Pers.) forage and on soil characteristics.

CHAPTER II

LITERATURE REVIEW

Sulfur is an essential element for plant growth and must be available in adequate amounts for maximum yield and high quality forage production. Sulfur is taken up primarily as the SO_4^{2-} ion by plants (37). Because SO_4^{2-} is subject to leaching (1, 17, 20), the amount of SO_4^{2-} retained by a given soil influences the available SO_4^{2-} for plant use. Soil type has an effect on S oxidation and reduction because of differences in numbers of soil bacteria among soils (4).

Crop deficiencies of S have been observed throughout the United States as well as in many regions of the world with increasing frequency over the past 25 years, and especially within the last 10 years. Sulfur deficiencies in high yielding Coastal bermudagrass have been observed in east Texas in recent years (23). Currently, more than 30 states have reported crop responses to applications of S (3, 25, 36). Possible cause for the recent concern for deficiencies of S is the use of essentially sulfur-free higher analysis fertilizers, increased crop yields, and new restrictions and regulations on air pollution control (9, 25). Sulfur deficiencies generally occur on sandy, well drained soils with low organic matter content, low soil pH, and which receive high annual rainfall or are under irrigation. Soil texture has a strong influence on the amount of S available in soils because of its relationship to leaching (19). Anderson and Kunkel (2) found that bermudagrass yields from ammonium sulfate fertilization were most frequently lower on a calcareous clay, but were continually high on a Lufkin fine sandy loam. On a Wagram sand, Rhue and Kamprath (30) found that most of the SO_4^{2-}-S was leached below 45 cm in 180 days. Soil analysis by Mueller et al. (26) revealed that at the 45 to 122 cm depth, the amount of SO_4^{2-}-S present was 2 to 8 times greater than the amount found in the 0 to 30 cm zone, thus suggesting that conventional soil sampling (0 to 15 cm depth) of sandy soil to determine S fertilizer requirements of bermudagrass is not advisable. Reports have indicated that S deficiency is often confused with N deficiency, but by careful examination the two can usually be distinguished (12, 14). A plant under stress of S deficiency translocates little S to young leaf tissue, thus causing the characteristic yellow color in the top or growing portion of the plant (22). When N is at critical level in a plant, it will be translocated out of the old tissue into young growing tissue, causing N deficiency symptoms on the lower portions of the plant. Barker (5) indicated that since N and S were both involved in the formation of protein, this was the reason for the similarity of deficiency symptoms. Sulfur is a constituent of some amino acids and is consequently involved in protein metabolism. Sulfur compounds which play an important role in protein structure include enzymes and electron carriers such as cytochromes (8). There are three essential sulfur-containing amino acids: cystine, cysteine, and methionine; and these three contain approximately 90% of all plant S (37).

Critical levels of sulfur ranging from 0.10 to over 0.30% have been suggested for many species of plants (13, 23, 32). Landua et al. (22) reported a 30% increase in forage production of Coastal bermudagrass on some sandy soils from S additions when grown with high N fertilization. They also suggested that a concentration of 0.15% S in forage to be critical. Bremer (7) demonstrated the need for S by Midland bermudagrass production on soil in a field that contained 26.9 kg ha^{-1} SO_4^{2-}-S. He suggested a critical plant S level of 0.10 to 0.15%. Yields were significantly increased in the upper coastal plain of North Carolina in 7 of 8 years on deep sandy soil by additions of S to Coastal bermudagrass (40). High rates of N have been shown to affect the uptake of secondary elements such as S by plants. In the Coastal Plains of Georgia, S combined with applications of N at rates of 336 to 672 kg ha^{-1} increased forage yields up to 5.5% (11).

Nitrogen-sulfur ratios are a comparison of N content versus the S content in plant tissue and can be used to diagnose S deficiencies (24, 31) and possibly N deficiencies (27) in plants; but because of the sensitivity of changes in the supply of N or S, the N/S ratio has been used increasingly as an index of the S status (24). However, on a study in eastern Oklahoma on bermudagrass, Westerman et al. (39) reported that no differences in total yield were observed from S applications. Although, it was noted that S uptake was increased and N/S ratios decreased due to the S application. In other studies, S fertilization has also been shown to decrease N/S ratios (18, 24, 26) and increase S levels in plant tissue in forage (18, 26) as well as in corn (29). The use of N/S ratios is limited in evaluating the S status of any crop by three important factors:

1. Very little data exist in the literature on acceptable ratios required for growth at different growth stages under field conditions.

2. The ratio has been shown to be extremely variable when the crop has adequate S nutrition.

3. Most importantly, a poor correlation exists between the ratio and yield (10, 16, 21, 28).

Various N/S ratios have been reported as being critical for different crops. Critical ratios vary from 1 to 15 for corn (35), 12 to 17 for bermudagrass (40), and 16 to 19 for wheat (33). Even though nutrient ratios can be helpful in determining the plant's nutrient status, Grant and Rowell (15) indicated that even in an acceptable ratio range it is possible to have two elements low in the plant tissue, thus requiring that individual element levels be considered when using nutrient ratios.

CHAPTER III

MATERIALS AND METHODS

A field study was initiated on 13 April 1984 near Hennepin, Oklahoma, in the W1/2 of the SW1/4 of the NW1/4 of the NE1/4 in Section 20, Township 1N, Range 1W, in Garvin county. The vegetation was established Midland bermudagrass. The soil was a Konsil loamy fine sand (Ultic Paleustalf) with a high potential for response to S fertilization.

The experiment consisted of a 5 x 5 factorial arrangement of treatments with 5 levels of N and S replicated 4 times in a randomized complete block design. Individual plots measured 6.1 x 15.2 m. Nitrogen was applied at levels of 0, 224a, 224a+168b, 224a+168b+168c, and 224a+168b+168c+168d kg/ha, respectively, where a, was applied 15 April 1984, and b, c, and d applications were to be applied after each successive harvest. However, due to limited rainfall the only additional level applied was b, on 17 July 1984. All S was applied on 15 April 1984 at levels of 0, 5.6, 11.2, 22.4, and 44.8 kg/ha. Ammonium sulfate (21-0-0-24) was the source of S for all treatments except those treatments of 0 kg/ha N where Cal-Sul (0-0-0-17.3) was used. Nitrogen was supplied using ammonium nitrate (34-0-0) and rates were adjusted to include the N supplied as ammonium sulfate when necessary.

Forage was harvested 27 June 1984 when approximately 45 cm in height with a 2.13 m Sperry-New Holland haybine mower conditioner by cutting a 2.13 m swath through the center of each plot. A 2.13 x 3.05 m area from each plot was weighed for the plot weight. A representative moisture sample was taken from each plot, weighed, then oven dried at 60°C for 48 h, then reweighed and production results were calculated and reported as dry matter yield (kg/ha). Dried samples were then ground with a Wiley Mill using a 1 mm sieve. Nitrogen content in the forage was determined by micro Kjeldahl analysis, and SO_4^{2-}-S content was determined after digestion and oxidation (6, 38) turbidimetrically using a Technicon autoanalyzer. Remaining forage was cut, baled, and removed from the field after each harvest and before the next application of fertilizer treatments. Single degree of freedom contrasts were computed for determination of linear, quadratic, or cubic effects due to S fertilization.

Soil samples were taken on 14 April 1984 at 8 depths from each plot before the application of fertilizer. Soil sampling depths were 0 to 15, 16 to 31, 32 to 46, 47 to 61, 62 to 76, 77 to 91, 92 to 107, and 108 to 122 cm. On 12 July 1984 soil samples were taken after the first harvest at all 8 depths from each plot. This was the last set of soil samples taken since there was only one forage harvest due to limited rainfall. Soil samples were analyzed for NO_3^--N using a NO_3^--N electrode after extraction with $CaSO_4$ and SO_4^{2-}-S was determined turbidimetrically using $Ba(OH)_2$).

On 30 April 1985 the study was relocated at the Wes Watkins Agricultural Research and Extension Center (WWAREC) at Lane, Oklahoma, in the NE1/4 of the NW1/4 of the NW1/4 in Section 12, Township 3S, Range

12E in Atoka county. The study was conducted two consecutive years, 1985 and 1986. The vegetation was established Midland bermudagrass. The soil was a Bernow fine sandy loam (Glossic Paleudalf) with a high potential for response to S fertilization.

The experiment consisted of a 5x5 factorial arrangement of treatments with 5 levels of N and 5 levels of S replicated 4 times in a randomized complete block design. Individual plots were 6.1 x 15.2 m.

On 10 May 1985 all forage was cut, baled, and removed from the field before fertilizer treatments were applied.

Nitrogen was applied at levels of 0, 224a, 224a+168b, 224a+168b +168c, and 224a+168b+168c+168d kg/ha, respectively, where a, was applied 24 May 1985 and 13 May 1986; b, c, and d applications were to be applied after successive harvest, but due to limited rainfall the only additional N level applied was b on 24 July 1985 and 11 July 1986. All S was applied on 24 May 1985 and 13 May 1986 at levels of 0, 5.6, 11.2, 22.4, and 44.8 Kg/ha. Ammonium sulfate (21-0-0-24) was the source of S for all fertilized treatments except those of 0 kg/ha N, where Cal-Sul (0-0-0-17.3) was used.

Nitrogen was supplied using ammonium nitrate (34-0-0) and rates were adjusted to include the N supplied as ammonium sulfate when necessary. Soil tests also showed there was a potassium (K) deficiency, so 67.2 kg/ha of K_2O (0-0-62) was applied 24 May 1985 and 13 May 1986. All fertilizer applications were broadcast with a 2.44 m calibrated output Barber fertilizer spreader.

Chemical applications of atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-S-triazine] at a rate of 1.68 kg/ha active ingredient were applied 24 May 1985 and 15 April 1986. On 1 August 1985, 2,4-D

[((2,4-dichlorophenoxy) acetic acid) dimethylamine] was applied at a rate of 1.12 kg/ha active ingredient for weed control. The herbicides were applied with a 3-point hydraulic sprayer at a speed of 6.44 km/h and a carrier volume of 257.1 ℓ/ha.

During 1985 and 1986, there were only two harvests each year due to low rainfall. Forage was harvested 16 July 1985, 16 October 1985, 25 June 1986, and 18 October 1986, respectively, when approximately 45 cm in height with a 2.13 m Sperry-New Holland haybine mower conditioner from a 2.13 x 3.05 m area from the center of each plot. Sample preparation, analysis, and forage removal were the same as previously described for the Hennepin location.

Rainfall data for Hennepin, 1984, and the WWAREC for 1985 and 1986 are reported in Appendix Tables I, II, and III, respectively.

Significant differences among means were determined using LSDs (0.05) calculated from error mean squares obtained from analysis of variance. Formulae used to calculate LSDs for comparisons are reported in Appendix Table IV. Correlations were performed using standard statistical procedures in SAS (34).

CHAPTER IV

RESULTS AND DISCUSSION

HENNEPIN, OKLAHOMA--1984

Due to limited rainfall from July to October, forage growth was reduced, thus permitting the removal of only one harvest at Hennepin in 1984. No actual precipitation data was available for Hennepin, so precipitation data from Healdton, Oklahoma, which is approximately 25 miles southwest of Hennepin, was used as an estimate (Appendix Table I). However, this data can only be used as an estimate because of the wide distance and the variances of rainfall in the area.

Dry Matter Yield

Soil moisture was adequate early in the growing season and application of 224 kg N ha^{-1} increased harvest yield greater than 40% over the check plot (Table 1). An additional 168 kg N ha^{-1} was applied after the first harvest but due to lack of moisture no forage was harvested. Yield was unresponsive to application of S regardless of rate, although the highest yield was obtained at the 224 kg N ha^{-1} combined with 44.8 kg S ha^{-1} (Table 1). There was no N by S interaction effects on harvest yield at Hennepin (Table 1). Moisture shortfalls limit plant root growth which curtails nutrient uptake,

Table 1. Nitrogen and sulfur effects on dry matter yield, N and S Concentration, N and S uptake, and N/S ratio in bermudagrass at Hennepin, 1984.

Rate N	Rate S	OBS	Yield	Conc. N	Conc. S	Uptake NUP	Uptake SUP	N/S Ratio
— kg/ha —			kg/ha	— g/kg —		—— kg/ha ——		
				Nitrogen				
0		20	3974	14.0	2.0	55.7	7.9	8.3
224		80	5807	20.0	2.0	111.6	10.6	12.9
LSD (0.05)			1057	2.0	1.0	23.9	2.0	4.4
OSL			0.01	0.00	0.38	0.01	0.02	0.05
				Sulfur				
	0	20	4980	18.0	1.0	88.3	6.3	15.0
	5.6	20	4511	19.0	2.0	88.1	7.7	12.1
	11.2	20	5528	18.0	2.0	94.7	10.3	9.9
	22.4	20	4456	16.0	2.0	69.7	10.5	7.7
	44.8	20	4981	15.0	3.0	77.5	11.5	8.5
LSD (0.05)			809	2.0	1.0	16.4	3.3	3.1
OSL			0.08	0.00	0.01	0.04	0.03	0.00
				Nitrogen x Sulfur				
0	0	4	4288	14.0	1.0	58.5	5.9	10.5
0	5.6	4	3313	16.0	2.0	53.1	5.5	10.8
0	11.2	4	5036	15.0	2.0	73.7	10.3	8.0
0	22.4	4	3504	13.0	2.0	45.6	7.6	6.9
0	44.8	4	3730	13.0	3.0	47.8	10.3	5.6
LSD (0.05)			1896	3.0	1.0	27.8	5.3	5.0
224	0	16	5671	21.0	1.0	118.1	6.7	19.5
224	5.6	16	5708	22.0	2.0	123.1	9.8	13.4
224	11.2	16	6020	20.0	2.0	115.7	10.2	11.7
224	22.4	16	5407	18.0	2.0	93.7	13.3	8.5
224	44.8	16	6232	17.0	2.0	107.1	12.7	11.3
LSD (0.05)			948	2.0	0.4	13.9	2.6	2.5
†LSD (0.05)			1499	3.0	1.0	21.9	4.2	3.9
OSL			0.50	0.34	0.40	0.37	0.24	0.09

†LSD (0.05) for comparison between any two treatment means.

thus not allowing complete nutrient utilization and resulting in less than maximum forage yields.

Nutrient Concentration

Nitrogen fertilization at 224 kg N ha^{-1} increased N concentration in forage substantially greater than observed in the zero N check plot (Table 1). There was no change in S concentration due to applied N regardless of rate of application (Table 1). A single degree of freedom contrast showed a significant negative linear response from applied S on N concentration in forage (Table 1). However, a significant positive linear response from a single degree of freedom contrast was observed from application of S on forage S concentration with the greatest effect occurring from application of 44.8 kg S ha^{-1} (Table 1). There were no interaction effects of N and S on nutrient concentration (Table 1).

Nutrient Uptake

Nitrogen fertilization increased N uptake with application of 224 kg N ha^{-1} twofold over 0 kg N ha^{-1} (Table 1). Sulfur uptake was significantly increased by application of 224 kg N ha^{-1} (Table 1). Sulfur rates 0, 5.6, and 11.2 Kg S ha^{-1} resulted in greater N uptake than obtained with 22.4 and 44.8 kg S ha^{-1} which was due to decreased N concentration in forage with increased S application (Table 1). Sulfur uptake was increased with each increment of added S with the greatest response occurring between the 0 and 11.2, 22.4, and 44.8 kg S ha^{-1} rates (Table 1). There was no N by S interaction effect observed on N or S uptake in forage at Hennepin (Table 1).

Nitrogen/Sulfur Ratio

The N/S ratio was increased from an N/S ratio of 8.3 at 0 kg N ha^{-1} to 12.9 from application of 224 kg N ha^{-1} (Table 1). Nitrogen/sulfur ratio was decreased with applied S at all rates except 5.6 kg S ha^{-1} (Table 1). The most significant N/S reduction was almost twofold with application of 44.8 kg S ha^{-1} (Table 1) when the N/S ratio was reduced from 15.0 to 8.5. There were no significant ($p \leq 0.05$) N by S interaction effects on N/S ratio (Table 1).

Dry Matter Yield--N/S Ratio Correlation

There was no significant correlation between dry matter yield and N/S ratio at Hennepin in 1984 (Table 2). Therefore, dry matter yield was not affected by N/S ratio in forage.

Initial Soil Characteristics

Due to the large number of missing data below 76 cm, only depths of 0 to 15, 16 to 31, 32 to 46, 47 to 61, and 62 to 76 cm were analyzed statistically and used in this discussion (Table 3).

The soil was slightly acidic and the pH increased with depth (Table 3). Nitrate N content in the soil was low and variable at all depths (Table 3). Soil P decreased from 22.2 ug P g^{-1} of soil at 0 to 15.2 cm to near 0 ug P g^{-1} of soil at 61.0 to 76.2 cm (Table 3). Potassium was higher in the subsoil than in the surface 31 cm (Table 3).

Sulfate S increased from 5.4 ± 1.8 ug S g^{-1} of soil in the top soil to 6.3 ± 1.8 ug S g^{-1} of soil in the subsoil (Table 3). In the

Table 2. Correlation of dry matter yield and N/S ratio at Hennepin in 1984 and WWAREC in 1985 and 1986.

Location	Year	Harvest	r	r^2	OSL
Hennepin	1984	1	-.0154	.0002	.879
Lane	1985	1	-.2486	.0618	.013
Lane	1985	2	.2177	.0474	.030
Lane	1985	1+2	-.2109	.0445	.036
Lane	1986	1	.1254	.0157	.214
Lane	1986	2	.0274	.0007	.787
Lane	1986	1+2	.0708	.0050	.484

Table 3. Soil characteristics at Hennepin prior to fertilization, 1984.

Depth	pH	NO_3^--N	P	K	SO_4^{2-}-S
(cm)		ug/g of soil			
0 - 15	5.42 ± .34	1.7 ± 1.1	22.2 ± 8.1	89.9 ± 36.7	5.4 ± 1.8
16 - 30	5.31 ± .30	1.1 ± 1.4	11.9 ± 8.9	67.3 ± 42.0	5.1 ± 1.8
31 - 46	5.57 ± .29	2.1 ± 1.5	3.9 ± 5.5	113.6 ± 50.0	6.2 ± 2.1
47 - 61	5.64 ± .30	2.5 ± 1.9	2.1 ± 3.4	132.5 ± 29.7	6.4 ± 2.1
62 - 76	5.71 ± .38	1.9 ± 1.0	0.8 ± 0.5	120.5 ± 21.0	6.3 ± 1.8

lower soil profile the percent clay content increased at Hennepin and because water movement is reduced through clay, the greatest accumulation of SO_4^{2-}-S was found in the subsoil.

Post Fertilization Soil Characteristics

Due to the large number of missing data below 76 cm, only depths of 0 to 15, 16 to 31, 32 to 46, 47 to 61, and 62 to 76 cm were analyzed statistically and used in this discussion (Tables 4 and 5).

Nitrogen increased NO_3^--N content in the soil, especially in the upper 31 cm, but had no effect on pH, P, K, or SO_4^{2-}-S (Tables 4 and 5). There was no response due to S on any soil characteristic regardless of rate (Table 4 and 5). Depth was the factor for either an increase or decrease in all soil characteristics (Tables 4 and 5).

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Due to limited rainfall (Appendix Table II) during the growing season, only two harvests were obtained.

Dry Matter Yield

First harvest yield was not increased from application of N (Table 6). Second harvest yield was increased with 224 kg N ha^{-1} applied initially, followed by 168 kg N ha^{-1} after first harvest (Table 7). Combined first plus second harvest yields were increased by 224 kg N ha^{-1} applied initially and 224 kg N ha^{-1} applied initially, followed by 168 kg N ha^{-1} after first harvest (Table 8). First, second, and combined first plus second harvest yields were not

Table 4. Soil characteristics at Hennepin after fertilization of nitrogen and sulfur, 1984.

Depth	OBS		S	pH		NO_3^--N		P		K		SO_4^{2-}-S	
	0	224 N		0	224 N	0	224 N	0	224 N	0	224 N	0	224 N
(cm)	kg/ha					ug/g of soil							
0-15	4	15	0	5.33	5.19	0.5	3.5	21	21	70	82	7.3	6.0
	4	15	5.6	5.18	4.99	0.5	2.8	24	23	63	64	7.5	7.6
	3	16	11.2	5.00	5.08	0.2	1.2	21	16	77	68	8.8	6.3
	4	16	22.4	5.20	5.08	0.5	2.0	21	23	78	68	8.6	7.6
	4	16	44.8	5.03	4.94	1.0	0.8	24	23	81	66	8.4	7.8
16-31	4	16	0	4.88	4.91	0.0	2.0	10	12	41	61	4.3	5.3
	4	16	5.6	4.73	4.85	0.0	2.7	11	9	44	55	5.0	6.0
	3	16	11.2	5.33	4.96	0.5	3.3	3	9	127	52	6.5	5.1
	4	16	22.4	4.93	4.96	0.0	1.1	9	9	50	69	4.9	5.9
	4	16	44.8	5.20	4.97	0.0	0.7	10	13	88	49	8.9	7.2
32-46	4	16	0	5.28	5.27	0.1	1.1	5	4	84	70	12.4	6.8
	4	16	5.6	5.43	5.27	0.0	3.0	1	3	112	77	7.9	6.4
	4	16	11.2	5.63	5.28	0.3	3.3	1	4	162	86	7.9	7.0
	4	16	22.4	5.43	5.30	0.0	1.3	7	3	70	119	6.3	8.0
	4	16	44.8	5.23	5.33	0.1	0.8	5	5	64	84	6.5	6.6
47-61	4	15	0	5.23	5.55	0.0	1.3	2	1	117	141	7.3	7.4
	3	16	5.6	5.73	5.51	1.2	2.3	1	1	140	139	8.5	7.8
	4	15	11.2	5.63	5.49	0.1	1.7	1	2	139	132	8.0	7.8
	4	15	22.4	5.63	5.57	0.1	0.7	1	1	121	143	9.5	9.9
	4	14	44.8	5.50	5.58	0.0	0.8	2	2	103	111	7.9	7.6
62-76	2	10	0	5.60	5.58	0.3	1.2	0	2	104	137	7.8	7.9
	3	14	5.6	5.50	5.51	0.0	1.9	1	2	108	120	9.2	7.3
	3	12	11.2	5.43	5.40	0.3	3.1	0	0	114	127	5.5	7.9
	3	8	22.4	5.27	5.56	0.2	1.4	0	1	133	120	8.2	7.1
	3	12	44.8	5.83	5.48	0.2	0.6	1	1	82	115	5.7	8.1

Table 5. Mean square error and observed significance level for soil characteristics after fertilization of nitrogen and sulfur, 1984.

Source	pH	NO_3^--N	P	K	SO_4^{2-}-S
		Mean square error			
N rate	.0321	25.23	26.73	2958.23	32.65
S rate	.1662	17.35	163.05	10182.11	83.63
N x S	.2652	18.37	148.84	9675.70	107.15
Depth	.0046	7.60	225.42	7297.81	28.73
N x D	.0856	10.06	38.90	3517.88	33.90
S x D	.1040	6.04	98.66	2074.00	48.28
N x S x D	.1104	3.96	133.73	2785.84	43.32
		Observed significance level			
N rate	.07	.02	.50	.98	.16
S rate	.93	.14	.23	.19	.93
N x S	.83	.22	.88	.12	.99
Depth	.00	.37	.00	.00	.01
N x D	.84	.67	.21	.26	.79
S x D	.23	.18	.61	.00	.30
N x S x D	.48	.22	.97	.01	.34

Table 6. Nitrogen and sulfur effects on dry matter yield, N and S concentration, N and S uptake, and N/S ratio in bermudagrass in the first harvest at WWAREC, 1985.

Rate N	Rate S	OBS	Yield	Conc. N	Conc. S	Uptake NUP	Uptake SUP	N/S Ratio
— kg/ha —			kg/ha	— g/kg —		— kg/ha —		
				Nitrogen				
0		20	4736	12.6	3.3	59.1	16.3	4.0
224		79	5657	16.5	3.2	91.6	18.6	5.4
LSD (0.05)			1572	4.1	0.3	41.7	4.7	1.1
OSL			0.16	0.06	0.43	0.09	0.20	0.03
				Sulfur				
	0	20	4656	14.4	3.1	65.4	14.8	5.1
	5.6	20	5593	14.1	3.0	80.8	17.0	4.9
	11.2	20	5049	15.3	3.4	78.5	17.1	4.7
	22.4	20	4983	14.6	3.5	69.6	17.5	4.6
	44.8	20	5667	14.6	3.6	81.9	20.4	4.3
LSD (0.05)			2315	1.6	0.6	35.4	8.7	1.2
OSL			0.87	0.61	0.19	0.81	0.76	0.67
				Nitrogen x Sulfur				
0	0	4	4826	12.4	3.2	58.8	17.0	4.2
0	5.6	4	4297	12.6	2.7	53.3	11.4	4.8
0	11.2	4	4769	12.9	3.4	65.8	16.7	3.8
0	22.4	4	4372	12.7	3.5	51.6	15.2	4.0
0	44.8	4	5417	12.4	3.9	66.1	20.9	3.3
LSD (0.05)			3582	2.9	1.0	56.5	15.5	1.6
224	0	15	4486	16.4	2.9	72.0	12.6	6.0
224	5.6	16	6888	15.6	3.3	108.3	22.6	4.9
224	11.2	16	5328	17.6	3.3	91.3	17.6	5.5
224	22.4	16	5593	16.5	3.4	87.7	19.9	5.2
224	44.8	16	5917	16.7	3.3	97.7	20.0	5.3
LSD (0.05)			1821	1.5	0.5	28.7	7.9	0.8
†LSD (0.05)			3120	2.5	0.8	49.7	13.5	1.4
OSL			0.63	0.82	0.27	0.71	0.41	0.24

†LSD (0.05) for comparison between any two treatment means.

Table 7. Nitrogen and sulfur effects on dry matter yield, N and S concentration, N and S uptake, and N/S ratio in bermudagrass in the second harvest at WWAREC, 1985.

Rate N	Rate S	OBS	Yield	Conc. N	Conc. S	Uptake NUP	Uptake SUP	N/S Ratio
—— kg/ha ——			kg/ha	—— g/kg ——		——kg/ha——		
				Nitrogen				
0		20	1078	9.3	2.4	9.8	2.7	4.1
224		20	1756	10.4	2.4	17.8	4.2	4.4
†224+168		60	2706	15.4	2.6	40.3	6.9	6.2
LSD (0.05) 0 vs. 224			828	3.2	0.4	11.8	2.2	1.3
LSD (0.05) 0 and 224 vs. 224+168			676	2.6	0.3	9.6	1.8	1.1
OSL			**0.00**	**0.00**	**0.32**	**0.00**	**0.00**	**0.00**
				Sulfur				
	0	20	1551	11.6	2.1	19.7	3.3	5.6
	5.6	20	1525	11.3	2.6	18.5	4.2	4.4
	11.2	20	1872	12.4	2.5	24.9	4.6	5.1
	22.4	20	2254	11.6	2.5	26.8	5.5	4.8
	44.8	20	2031	11.5	2.7	23.3	5.5	4.4
LSD (0.05)			756	1.3	0.3	7.5	1.8	0.8
OSL			0.23	**0.48**	0.02	**0.14**	0.10	**0.03**
				Nitrogen x Sulfur				
0	0	4	819	10.0	1.9	8.1	1.5	5.3
0	5.6	4	1206	9.4	2.6	11.0	3.4	3.9
0	11.2	4	1079	9.2	2.4	10.0	2.6	3.9
0	22.4	4	937	8.4	2.5	7.2	2.4	3.5
0	44.8	4	1348	9.5	2.7	12.8	3.6	3.8
224	0	4	1323	9.3	2.0	11.3	2.5	4.6
224	5.6	4	1063	9.9	2.5	11.4	2.7	3.9
224	11.2	4	1466	11.1	2.6	15.9	3.7	4.5
224	22.4	4	2961	11.7	2.4	32.6	7.1	5.0
224	44.8	4	1968	10.0	2.6	17.9	5.0	4.0
LSD (0.05)			1314	3.1	0.7	14.6	3.3	1.7
224+168	0	12	2511	15.4	2.3	39.7	5.7	6.9
224+168	5.6	12	2307	14.7	2.7	33.0	6.3	5.5
224+168	11.2	12	3070	16.8	2.5	48.7	7.7	7.0
224+168	22.4	12	2864	14.8	2.6	41.1	7.2	6.0
224+168	44.8	12	2776	15.1	2.8	39.2	7.7	5.4
LSD (0.05)			759	1.8	0.4	8.4	1.9	1.0
‡LSD (0.05)			1073	2.5	0.6	11.9	2.7	1.4
OSL			**0.37**	**0.57**	**0.99**	**0.10**	**0.45**	**0.47**

†Indicates 224 kg N ha^{-1} applied initially followed by 168 kg N ha^{-1} after first harvest.

‡LSD (0.05) for comparison between any two treatment means.

Table 8. Nitrogen and sulfur effects on dry matter yield, N and S concentration, N and S uptake, and N/S ratio in bermudagrass in the sum of the first plus second harvests at WWAREC, 1985.

Rate N	Rate S	OBS	Yield	Conc. N	Conc. S	Uptake NUP	Uptake SUP	N/S Ratio
kg/ha	kg/ha		kg/ha	g/kg	g/kg	kg/ha	kg/ha	
Nitrogen								
0		20	5814	11.0	2.9	68.9	18.9	4.0
224		20	7908	13.9	2.9	121.7	25.6	5.1
†224+168		59	8171	15.8	2.9	127.6	24.5	5.6
LSD (0.05) 0 vs. 224			1537	2.2	0.3	34.0	4.2	0.9
LSD (0.05) 0 and 224 vs. 224+168			1258	1.8	0.3	27.8	3.5	0.8
OSL			0.01	0.00	0.96	0.01	0.01	0.01
Sulfur								
	0	20	6228	13.3	2.5	87.0	17.6	5.4
	5.6	20	7704	13.0	2.9	110.7	24.2	4.7
	11.2	20	7028	14.3	3.0	110.1	22.2	4.9
	22.4	20	7469	13.9	2.9	107.3	23.7	5.1
	44.8	20	8061	13.4	3.2	115.3	27.2	4.4
LSD (0.05)			2128	1.1	0.4	32.0	8.2	1.1
OSL			0.45	0.11	0.05	0.41	0.22	0.39
Nitrogen x Sulfur								
0	0	4	5645	11.2	2.6	66.9	18.6	4.3
0	5.6	4	5504	11.0	2.6	64.3	14.8	4.5
0	11.2	4	5848	11.1	2.9	75.8	19.3	3.7
0	22.4	4	5309	10.6	3.0	58.8	17.6	3.9
0	44.8	4	6766	11.0	3.3	78.9	24.5	3.4
224	0	4	6210	12.7	2.4	82.0	16.9	5.5
224	5.6	4	8644	12.7	3.1	129.8	30.6	4.4
224	11.2	4	6861	14.7	3.1	118.1	22.4	5.1
224	22.4	4	8685	16.2	2.8	141.2	26.2	6.4
224	44.8	4	9141	13.3	3.2	137.1	31.8	4.3
LSD (0.05)			3834	3.4	0.7	51.6	15.0	1.9
224+168	0	11	6830	16.0	2.6	112.2	17.5	6.4
224+168	5.6	12	8963	15.2	3.0	138.0	27.2	5.2
224+168	11.2	12	8375	17.1	2.9	136.4	24.8	6.0
224+168	22.4	12	8413	15.0	3.0	121.8	27.3	5.1
224+168	44.8	12	8275	15.9	3.0	129.7	25.5	5.4
LSD (0.05)			2264	2.0	0.4	30.5	8.8	1.1
‡LSD (0.05)			3131	2.8	0.6	42.2	12.2	1.6
OSL			0.91	0.43	0.71	0.69	0.71	0.36

†Indicates 224 kg N ha^{-1} applied initially followed by 168 kg N ha^{-1} after first harvest.

‡LSD (0.05) for comparison between any two treatment means.

increased with S fertilization regardless of rate (Tables 6, 7, 8). There were no interaction effects on yield from N and S applications for first, second, or combined first plus second harvests (Tables 6, 7, 8).

Nutrient Concentration

Nitrogen fertilization did not increase N concentration in forage during the first harvest (Table 6). Second harvest N concentration was only increased by 224 kg N ha^{-1} applied initially, followed by 168 kg N ha^{-1} after the first harvest (Table 7). Nitrogen rates, 224 kg N ha^{-1} initially and 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} both increased N concentration in forage for the combined first plus second harvests (Table 8). Applied N did not increase S concentration in the forage for either the first, second, or combined first plus second harvests (Tables 6, 7, 8). Sulfur, regardless of rate, had no effect on N concentration in forage for either the first, second, or combined first plus second harvests (Tables 6, 7, 8). No increase was observed on S concentration for any rate of S for the first harvest (Table 6). In contrast, S concentration was increased with all rates of S for the second harvest (Table 7). For the combined first plus second harvest, 11.2 kg S ha^{-1} and 44.8 kg S ha^{-1} increased S concentration in forage (Table 8). Nitrogen and S had no interactive effect on N or S concentration in forage for the first, second, or combined first plus second harvests (Tables 6, 7, 8).

Nutrient Uptake

Even though N uptake increased 54% due to application of 224 kg N

ha^{-1} in the first harvest, it was not significant ($p \leq 0.05$) (Table 6). Second harvest N fertilization at rate 224 kg N ha^{-1} applied initially, followed by 168 kg N ha^{-1} after first harvest increased N uptake (Table 7). Combined first plus second harvest N uptake was increased by 224 kg N ha^{-1} applied initially and 224 kg N ha^{-1} applied initially, followed by 168 kg N ha^{-1} after first harvest (Table 8). Sulfur uptake was not increased from applied N for first harvest (Table 6). Sulfur uptake in forage in the second harvest was increased by 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} (Table 7). Nitrogen application at rates 224 kg N ha^{-1} initially and 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest, increased S uptake for the combined first plus second harvests (Table 8). Sulfur fertilization did not increase N uptake in forage for either the first, second, or combined first plus second harvests (Tables 6, 7, 8). First harvest S application did not increase S uptake in forage (Table 6). Second harvest S rates 22.4 kg S ha^{-1} and 44.8 kg S ha^{-1} increased S uptake (Table 7). Combined first plus second harvest S uptake was increased by 44.8 kg S ha^{-1} initially (Table 8). There was no increase in N uptake or S uptake from an N by S interaction for the first, second, or combined first plus second harvests (Tables 6, 7, 8).

Nitrogen/Sulfur Ratio

Nitrogen/sulfur ratio was increased from N application of 224 kg N ha^{-1} in the first harvest (Table 6). Second harvest N/S ratio was increased by the 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest rate (Table 7). Nitrogen/sulfur ratio was increased from the application of 224 kg N ha^{-1} initially and 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest for the combined first plus second harvests (Table 8).

There was no decrease in N/S ratio for first harvest from S fertilization (Table 6). Sulfur rates of 5.6 kg S ha^{-1} and 44.8 kg S ha^{-1} initially decreased N/S ratios in forage in the second harvest (Table 7). Combined first plus second harvests indicated no decrease in N/S ratio for any S rate (Table 8).

Dry Matter Yield--N/S Ratio Correlation

First harvest had a negative correlation with N/S ratio; therefore, as N/S ratio decreased, dry matter yield increased (Table 2). Dry matter yield and N/S ratio had a positive correlation for second harvest with dry matter yield increasing as N/S ratio increased (Table 2). Combined first plus second harvests had a negative correlation which indicates that as N/S increases, the dry matter yield decreases (Table 2).

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Due to limited rainfall during the growing season, only two harvests were obtained. The total precipitation between the first harvest and the second harvest was fairly high, but 22.0 of the 34.7 cm for the period came during September when forage growth was beginning to decrease due to cooler temperature (Appendix Table III).

Dry Matter Yield

First harvest yield was not increased by N fertilization (Table 9). Second harvest yield was increased with application of 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest (Table 10). The N rate of 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest increased yield in the combined first plus second harvests (Table 11). Sulfur at rates 5.6 kg S ha^{-1} and 448 kg S ha^{-1} decreased yields in first harvest (Table 9). There was no increase or decrease in yield due to S application on second harvest (Table 10). Combined first plus second harvests yield was not increased by S regardless of rate (Table 11). There was no N by S interaction on yield for the first or second harvests (Tables 9, 10). In contrast, there was an interaction effect between N and S rates on the combined first plus second harvests (Table 11).

Nutrient Concentration

Nitrogen fertilization increased N concentration in forage first harvest (Table 9). Second harvest N concentration increased from N rate 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest (Table 10). Both N rates, 224 kg N ha^{-1} initially and 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest increased N concentration for the combined first plus second harvests (Table 11). There was no increase or decrease in N concentration from S application regardless of rate for either the first, second, or combined first plus second harvests (Tables 9, 10,11). There were no N by S interaction effects on N concentration for the first, second,

Table 9. Nitrogen and sulfur effects on dry matter yield, N and S concentration, N and S uptake, and N/S ratio in bermudagrass in the first harvest at WWAREC, 1986.

Rate N	Rate S	OBS	Yield	Conc. N	Conc. S	Uptake NUP	Uptake SUP	N/S Ratio
—kg/ha—			kg/ha	—g/kg—		—kg/ha—		
				Nitrogen				
0		20	4037	9.4	3.4	38.3	13.7	2.9
224		80	4619	12.2	2.9	55.8	13.2	4.5
LSD (0.05)			726	0.7	0.8	5.2	3.4	1.1
OSL			0.08	0.00	0.15	0.00	0.65	0.02
				Sulfur				
	0	20	4969	10.9	2.8	55.0	13.5	4.3
	5.6	20	3982	11.3	3.0	45.3	11.7	4.0
	11.2	20	4704	11.4	3.3	52.3	16.0	3.7
	22.4	20	4232	10.5	3.5	43.3	14.4	3.3
	44.8	20	3755	10.0	3.2	39.4	11.6	3.4
LSD (0.05)			828	1.6	0.5	12.0	3.2	0.7
OSL			0.04	0.39	0.08	0.08	0.05	0.05
				Nitrogen x Sulfur				
0	0	4	4749	10.0	3.0	49.5	14.2	3.5
0	5.6	4	3482	10.5	2.9	37.0	10.1	3.7
0	11.2	4	5068	9.5	3.7	48.4	19.1	2.7
0	22.4	4	4467	8.0	3.7	35.5	16.2	2.2
0	44.8	4	2420	8.8	3.5	21.1	8.8	2.6
LSD (0.05)			2103	3.2	1.0	30.6	7.0	1.4
224	0	16	5188	11.7	2.5	60.5	12.7	5.0
224	5.6	16	4481	12.0	3.0	53.6	13.2	4.3
224	11.2	16	4340	13.2	2.9	56.2	12.9	4.7
224	22.4	16	3997	13.0	3.2	51.2	12.6	4.4
224	44.8	16	5089	11.2	2.9	57.6	14.4	4.1
LSD (0.05)			1051	1.6	0.5	15.3	3.5	0.7
†LSD (0.05)			1662	2.5	0.8	24.2	5.6	1.1
OSL			0.05	0.25	0.56	0.44	0.04	0.27

†LSD (0.05) for comparison between any two treatment means.

Table 10. Nitrogen and sulfur effects on dry matter yield, N and S concentration, N and S uptake, and N/S ratio in bermudagrass in the second harvest at WWAREC, 1986.

Rate N	Rate S	OBS	Yield	Conc. N	Conc. S	Uptake NUP	Uptake SUP	N/S Ratio
—— kg/ha ——			kg/ha	—— g/kg ——		—— kg/ha ——		
				Nitrogen				
0		20	3042	10.2	3.5	30.7	10.7	3.0
224		20	3372	10.7	3.3	35.3	11.3	3.3
†224+168		60	5487	13.8	3.5	74.3	19.2	4.1
LSD (0.05) 0 vs. 224			1279	0.8	0.6	12.8	5.5	0.7
LSD (0.05) 0 and 224 vs. 224+168			1045	0.7	0.5	10.4	4.5	0.6
OSL			**0.00**	**0.00**	**0.65**	**0.00**	**0.00**	**0.01**
				Sulfur				
	0	20	3627	12.2	3.4	45.0	12.4	3.7
	5.6	20	3746	11.7	3.4	45.8	12.6	3.5
	11.2	20	4007	11.5	3.5	45.8	14.1	3.4
	22.4	20	4106	11.2	3.7	47.3	14.6	3.2
	44.8	20	4348	11.2	3.3	50.1	14.9	3.5
LSD (0.05)			942	2.3	0.4	9.9	3.3	0.8
OSL			**0.50**	**0.89**	**0.51**	**0.81**	**0.37**	**0.73**
				Nitrogen x Sulfur				
0	0	4	2631	11.3	3.5	28.0	9.4	3.4
0	5.6	4	2770	9.4	3.5	27.9	9.5	2.7
0	11.2	4	3359	9.6	3.8	31.6	12.6	2.5
0	22.4	4	3387	10.6	3.9	36.5	12.3	2.8
0	44.8	4	3064	10.0	3.0	29.6	9.4	3.5
224	0	4	2892	11.3	3.2	33.0	9.6	3.5
224	5.6	4	3278	11.4	3.3	36.2	10.7	3.5
224	11.2	4	3537	11.0	3.2	37.7	11.7	3.6
224	22.4	4	3473	10.1	3.6	34.6	12.4	2.8
224	44.8	4	3642	9.9	3.3	35.1	12.1	3.1
LSD (0.05)			1474	3.0	0.9	18.0	6.4	1.2
224+168	0	12	5359	13.9	3.4	74.0	18.1	4.2
224+168	5.6	12	5191	14.4	3.4	73.2	17.7	4.3
224+168	11.2	12	5090	13.9	3.5	68.0	17.8	4.2
224+168	22.4	12	5457	13.0	3.5	70.7	19.2	3.9
224+168	44.8	12	6338	13.6	3.7	85.6	23.3	3.8
LSD (0.05)			851	1.7	0.5	10.4	3.7	0.7
‡LSD (0.05)			1203	2.4	0.7	14.7	5.2	1.0
OSL			**0.70**	**0.85**	**0.57**	**0.41**	**0.48**	**0.57**

†Indicates 224 kg N ha^{-1} applied initially followed by 168 kg N ha^{-1} after first harvest.

‡LSD (0.05) for comparison between any two treatment means.

Table 11. Nitrogen and sulfur effects on dry matter yield, N and S concentration, N and S uptake, and N/S ratio in bermudagrass in the sum of the first plus second harvests at WWAREC, 1986.

Rate N	Rate S	OBS	Yield	Conc. N	Conc. S	Uptake NUP	Uptake SUP	N/S Ratio
—— kg/ha ——			kg/ha	—— g/kg ——		—— kg/ha ——		
				Nitrogen				
0		20	7079	9.8	3.5	69.0	24.3	3.0
224		20	7601	11.7	3.3	87.5	24.9	3.7
†224+168		60	10236	13.0	3.2	131.3	32.2	4.2
LSD (0.05) 0 vs. 224			1757	0.5	0.5	18.1	8.7	0.6
LSD (0.05) 0 and 224 vs. 224+168			1435	0.4	0.4	14.8	7.1	0.5
OSL			**0.00**	**0.00**	**0.26**	**0.00**	**0.04**	**0.00**
				Sulfur				
	0	20	8347	11.7	3.1	98.6	25.2	3.9
	5.6	20	7976	11.6	3.2	94.4	25.1	3.8
	11.2	20	8661	11.8	3.5	99.9	29.9	3.6
	22.4	20	8006	11.5	3.5	90.6	27.7	3.4
	44.8	20	8536	10.8	3.3	96.0	27.9	3.5
LSD (0.05)			1516	1.2	0.4	14.1	5.6	0.6
OSL			**0.81**	**0.46**	**0.15**	**0.64**	**0.34**	**0.28**
				Nitrogen x Sulfur				
0	0	4	7379	10.7	3.3	77.5	23.6	3.3
0	5.6	4	6252	10.0	3.2	64.9	19.6	3.3
0	11.2	4	8427	9.6	3.8	80.0	31.7	2.6
0	22.4	4	7854	9.3	3.8	72.0	28.6	2.5
0	44.8	4	5784	9.4	3.3	50.7	18.1	3.1
224	0	4	6633	11.5	3.0	79.3	20.4	3.9
224	5.6	4	8125	11.6	3.2	93.0	25.0	3.7
224	11.2	4	8232	12.4	3.4	96.3	28.7	3.8
224	22.4	4	6332	12.2	3.5	74.0	21.8	3.6
224	44.8	4	8683	10.7	3.3	94.9	28.4	3.4
LSD (0.05)			2481	2.6	0.7	33.6	9.6	1.4
224+168	0	12	11029	12.8	2.9	139.1	31.5	4.5
224+168	5.6	12	9550	13.3	3.2	125.7	30.6	4.3
224+168	11.2	12	9324	13.5	3.1	123.3	29.3	4.5
224+168	22.4	12	9833	12.8	3.3	125.8	32.8	4.0
224+168	44.8	12	11442	12.4	3.3	142.4	37.1	3.9
LSD (0.05)			1432	1.5	0.4	19.4	5.5	0.8
‡LSD (0.05)			2026	2.1	0.6	27.4	7.8	1.1
OSL			**0.02**	**0.93**	**0.77**	**0.25**	**0.03**	**0.93**

†Indicates 224 kg N ha^{-1} applied initially followed by 168 kg N ha^{-1} after first harvest.

‡LSD (0.05) for comparison between any two treatment means.

or combined first plus second harvests (Tables 9, 10, 11). Nitrogen application regardless of rate did not increase or decrease S concentration in forage for first, second, or combined first plus second harvests (Tables 9, 10, 11). Sulfur rate 22.4 kg S ha^{-1} increased S concentration in the first and combined first plus second harvests (Tables 9, 11). In contrast, S application did not increase S concentration in second harvest regardless of rate (Table 10). There was no interaction between N and S on S concentration for the first, second, or combined first plus second harvests (Tables 9, 10, 11).

Nutrient Uptake

First harvest N uptake was increased from N fertilization (Table 9). Second harvest N uptake was increased with 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest (Table 10). Combined first plus second harvests N uptake was increased by 224 kg N ha^{-1} initially and 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest (Table 11). First harvest S application decreased N uptake with 44.8 kg S ha^{-1} (Table 9). Sulfur did not increase or decrease N uptake in the second or combined first plus second harvests (Tables 10, 11). Nitrogen and S application had no interaction effect on N uptake for the first, second, or combined first plus second harvests (Tables 9, 10, 11). There was no response to N fertilization on S uptake for first harvest (Table 9). Sulfur uptake was increased with 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest for second and combined first plus harvests (Tables 10, 11). Sulfur uptake was decreased at rates 5.6 kg S ha^{-1} and 44.8 kg S ha^{-1} for first uptake (Table 9). Sulfur uptake was not increased by S regardless of rate for second or combined first plus second harvests (Tables 10, 11). There was a N by A interaction effect for both first and combined first plus second harvests (Tables 9, 11). In contrast, there was no interaction between N and S for second harvest (Table 10).

Nitrogen/Sulfur Ratio

First harvest N/S ratio in forage was increased with 224 kg N ha^{-1} (Table 9). Nitrogen fertilization at 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest increased N/S ratio in forage in the second harvest (Table 10). Combined first plus second harvests N/S ratio in forage was increased with 224 kg N ha^{-1} initially and 224 kg N ha^{-1} initially, followed by 168 kg N ha^{-1} after first harvest (Table 11). Sulfur rates 22.4 kg S ha^{-1} and 44.8 kg S ha^{-1} decreased N/S ratio in first harvest (Table 9). Second and combined first plus second harvest was not decreased from S fertilization regardless of rate (Tables 10, 11). There were no N by S interaction effects for the first, second, or combined first plus second harvests (Tables 9, 10, 11).

Dry Matter Yield--N/S Ratio Correlation

There was no correlation between dry matter yield and N/S ratio for the first, second, or combined plus second harvests (Table 2).

CHAPTER V

SUMMARY AND CONCLUSIONS

Nitrogen application increased dry matter yield, N concentration, N and S uptake, and N/S ratio, but had no effect on S concentration in forage at Hennepin, Oklahoma, in 1984. Sulfur application increased S concentration and S uptake and decreased N concentration, N uptake, and N/S ratio, but had no effect on dry matter yield. There were no N by S interaction effects on dry matter yield, nutrient concentration, nutrient uptake, or N/S ratio in forage and there was no correlation between dry matter yield and N/S ratio. Nitrogen fertilization increased NO_3^--N content in the soil, but had no significant effect on pH, P, K, or SO_4^{2-}-S. There was no significant change in soil characteristics due to S application.

Nitrogen increased N/S ratio but had no effect on dry matter yield, nutrient concentration, or nutrient uptake in forage for the first harvest at the Wes Watkins Agricultural Research and Extension Center in 1985. Nitrogen increased dry matter yield, N concentration, nutrient uptake, and N/S ratio in the second and sum of both harvests. There was no significant response due to added S on first harvest. Howver, significant increases from S application were observed on S concentration and S uptake in the second and sum of both harvests. Nitrogen/sulfur ratio in forage was decreased by S application in the second harvest. There were no N x S interaction effects on the first, second, or sum of both harvests. There was a negative correlation between dry matter yield and N/S ratio in the first and sum of both harvests and a positive correlation for the second harvest.

Nitrogen fertilization increased N concentration, N uptake, and N/S ratio in forage in the first harvest at the Wes Watkins Agricultural Research and Extension Center in 1986. Nitrogen increased dry matter yield, N concentration, N and S uptake, and N/S ratio in the second and sum of both harvests. Sulfur application decreased dry matter yield, N uptake, and N/S ratio in the first harvest but increased S concentration. There was no response due to S application for the second or sum of both harvests with the exception of increased S concentration in the sum of both harvests. There was a N x S interaction effect on S uptake in the first harvest and dry matter yield and S uptake in the sum of both harvests. There was no correlation between dry matter yield and N/S ratio in forage for the first, second, or sum of both harvests.

In conclusion, the results of this study show that there was no S deficiency at either location, although it might be possible to get a response to S if continued high forage yields were harvested from these locations over a period of years. Results obtained from this study on S fertilization also relate to results observed by Westerman et al. (39) on a bermudagrass study in eastern Oklahoma.

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APPENDIX

Table I. Precipitation at Healdton[†] during 1984.

Month	cm	Month	cm
January	3.1	July	2.6
February	3.8	August	3.2
March	14.2	September	3.1
April	5.3	October	23.9
May	10.4	November	8.2
June	12.0	December	8.6
[‡]Total (4/15-6/27/84)	23.9		
[§]Total (6/27-10/17/84)	14.3		
Total (Year)	98.4		

[†]Healdton was the closest official weather reporting station near Hennepin.

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

[§]Total amount of rainfall from first harvest until approximate time second harvest should have occurred.

Table II. Precipitation at WWAREC during 1985.

Month	cm	Month	cm
January	5.3	July	9.1
February	7.5	August	4.3
March	14.6	September	8.2
April	25.6	October	15.9
May	10.4	November	12.9
June	15.2	December	1.1
†Total (5/24-7/16/85)	25.0		
‡Total (7/16-10/16/85)	16.0		
Total (Year)	130.1		

†Total amount of rainfall from initial fertilization until first harvest.

‡Total amount of rainfall from first harvest until second harvest.

Table III. Precipitation at WWAREC during 1986.

Month	cm	Month	cm
January	0.2	July	0.7
February	9.4	August	5.4
March	7.0	September	22.0
April	15.9	October	6.9
May	17.9	November	14.2
June	13.4	December	1.7
†Total (5/13-6/25/86)	22.9		
‡Total (6/25-10/18/86)	34.7		
Total (Year)	114.7		

†Total amount of rainfall from initial fertilization until first harvest.

‡Total amount of rainfall from first harvest until second harvest.

Table IV. Calculations of least significant difference (LSD (0.05)) for forage for Hennepin and WWAREC.

N	S	Location	Year	Harvest	Calculation LSD (0.05)
—— kg/ha ——					
0 224		Hennepin Lane	1984 1986	1 1	$t\alpha_{.05}\sqrt{MSE\ (1.20 + 1/80)}$ df = 3 MSE = REP x NRATE
0 224		Lane	1985	1	$t\alpha_{.05}\sqrt{MSE\ (1/20 + 1/79)}$ df = 3 MSE = REP x NRATE
	0 5.6 11.2 22.4 44.8	Hennepin Lane Lane	1984 1985 1986	1 1 1	$t\alpha_{.05}\sqrt{1/4(1/4+1/4+1/16+1/16)\ MSE}$ df = 12 MSE = REP x SRATE
0 0 0 0 0	0 5.6 11.2 22.4 44.8	Hennepin Lane Lane	1984 1985 1986	1 1 1	$t\alpha_{.05}\sqrt{\frac{2MSE}{4}}$ df = 12 MSE = REP x NRATE x SRATE
224 224 224 224 224	0 5.6 11.2 22.4 44.8	Hennepin Lane	1984 1986	1 1	$t\alpha_{.05}\sqrt{\frac{2MSE}{16}}$ df = 12 MSE = REP x NRATE x SRATE
224 224 224 224	0 5.6 11.2 44.8	Lane	1985	1	$t\alpha_{.05}\sqrt{MSE\ (1/15+1/16)}$ df = 12 MSE = REP x NRATE x SRATE
0 0 0 0 0	0 5.6 11.2 22.4 44.8	Hennepin Lane	1984 1986	1 1	$t\alpha_{.05}\sqrt{MSE\ (1/4+1/16)}$ df = 12 MSE = REP x NRATE x SRATE
224 224 224 224 224	0 5.6 11.2 22.4 44.8	Lane	1985	1	$t\alpha_{.05}\sqrt{MSE\ (1/4+1/15+1/16)}$ df = 12 MSE = REP x NRATE x SRATE
0 224		Lane Lane Lane Lane	1985 1985 1986 1986	2 1+2 2 1+2	$t\alpha_{.05}\sqrt{\frac{2MSE}{20}}$ df = 6 MSE = REP x NRATE

Table IV. (Continued)

N	S	Location	Year	Harvest	Calculation LSD (0.05)
—— kg/ha ——					
0					$t\alpha_{.05}\sqrt{MSE\ (1/20+1/59)}$
224		Lane	1985	1+2	
224+168					df = 6 MSE = REP x NRATE
0		Lane	1985	2	$t\alpha_{.05}\sqrt{MSE\ (1/20+1/60)}$
224		Lane	1986	2	
224+168		Lane	1986	1+2	df = 6 MSE = REP x NRATE
	0				
	5.6	Lane	1985	2	
	11.2	Lane	1985	1+2	$t\alpha_{.05}\sqrt{1/9(1/4+1/4+1/4+1/4+1/12+1/12)\ MSE}$
	22.4	Lane	1986	2	df = 12 MSE = REP x SRATE
	44.8	Lane	1986	1+2	
0	0				
0	5.6				
0	11.2				
0	22.4	Lane	1985	2	
0	44.8	Lane	1985	1+2	$t\alpha_{.05}\sqrt{\frac{2MSE}{4}}$
224	0	Lane	1986	2	
224	5.6	Lane	1986	1+2	df = 24 MSE = REP x NRATE x SRATE
224	11.2				
224	22.4				
224	44.8				
224+168	0				
224+168	5.6	Lane	1985	2	$t\alpha_{.05}\sqrt{\frac{2MSE}{12}}$
224+168	11.2	Lane	1985	1+2	
224+168	22.4	Lane	1986	2	df = 24 MSE = REP x NRATE x SRATE
224+168	44.8	Lane	1986	1+2	
0	0				
0	5.6				
0	11.2				
0	22.4				
0	44.8				
224	0				
224	5.6	Lane	1985	2	
224	11.2	Lane	1985	1+2	$t\alpha_{.05}\sqrt{MSE\ (1/4+1/12)}$
224	22.4	Lane	1986	2	
224	44.8	Lane	1986	1+2	df = 24 MSE = REP x NRATE x SRATE
224+168	0				
224+168	5.6				
224+168	11.2				
224+168	22.4				
224+168	44.8				

VITA

Carl Eugene Woods, Jr.

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF NITROGEN AND SULFUR ON YIELD, NUTRIENT UPTAKE, AND N/S RATIOS IN BERMUDAGRASS

Major Field: Agronomy

Biographical:

Personal Data: Born in Cushing, Oklahoma, July 8, 1961, the son of Carl and Rosa Woods.

Education: Graduated from C. E. Donart High School, Stillwater, Oklahoma, in May, 1979; received the Bachelor of Science degree from Oklahoma State University in May, 1983; completed the requirements for a Master of Science degree at Oklahoma State University in May, 1987.

Professional Experience: Raised and worked on the Agronomy Research Station from childhood; worked as a research assistant in the Weed Science Research Program, Oklahoma State University, 1978-1983; employed as a Senior Agriculturist for the Soil Science Research Program, 1983-1987.

Professional Organizations: Member of the American Society of Agronomy; Crop Science Society of America; Soil Science Society of America; State of Oklahoma Research and Development Pesticide Applicator.