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USE OF PHOSPHOGYPSUM TO INCREASE YIELD AND QUALITY OF ANNUAL FORAGES

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USE OF PHOSPHOGYPSUM TO INCREASE YIELD AND QUALITY OF ANNUAL FORAGES

FINAL REPORT

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Phosphogypsum is a by-product of the wet-acid production of phosphoric acid. By the end of 1989, more than 600 million tons will have accumulated in Florida, with about 30 million tons being added annually. A high priority research area at the Florida Institute of Phosphate Research has been to investigate potential uses for phosphogypsum in industry and agriculture. This project is one of several funded by the Institute to examine the use of phosphogypsum as an agricultural soil amendment.

In this report, Dr. Greg Mullins of Auburn University has examined the use of gypsum as a sulfur fertilizer for annual forages (FIPR Project No. 85-01-048). His research has shown increases in forage quality and yield due to the sulfur in gypsum, which depend not only on the amount but also on the season of application. The need for sulfur fertilization was greater under a reduced tillage system than with conventional tillage. Soil and plant tissue samples have been analyzed for radium and polonium radionuclide concentrations. The analyses have shown no effects of phosphogypsum, applied at 40 pounds sulfur (260 pounds phosphogypsum) per acre, on radionuclide concentrations in either plants or soils.

In related work, Dr. Arvel Hunter of Agro Services International has described how the application of by-product gypsum alone and in combination with other nutrients and additives affected yields and nutrient contents of various crops grown on sandy, low-cation-exchange soils in Florida (FIPR Project No. 84-01-034). Gypsum application resulted in increased yields of several crops, including corn, potatoes, cantaloupes and watermelons. An important point of this research was that the benefits of the calcium and sulfur in gypsum might not be fully realized unless other nutrient deficiencies in the soils are also corrected. The study also found no significant effects of 0.5 to 1.5 tons of phosphogypsum per acre on radioactivity (gross alpha and gross beta emissions) or concentrations of arsenic, copper, iron, manganese, cadmium, vanadium, or zinc in several vegetable and fruit crops.

Dr. William Miller of the University of Georgia has demonstrated how surface-applied gypsum could reduce soil crusting, improve infiltration of rainwater, and reduce soil erosion in several highly weathered soils in Georgia (FIPR Project No. 83-01-020). The beneficial effects of gypsum were most striking in a heavier sandy clay loam, but lighter sandy loams also responded.

In other work at the University of Georgia (FIPR Project No. 83-01-024R) Dr. Malcolm Sumner has shown that by-product gypsum is effective in increasing yields of several field crops grown on acid soils by ameliorating aluminum toxicity and supplying additional calcium. Gypsum has an advantage over lime in that the slightly greater solubility of gypsum makes surface application possible, whereas lime often must be tilled deeply into the soil to be as effective.

Another project (FIPR No. 87-01-059) culminated in the publication of a comprehensive review article:

Shainberg, I., M.E. Sumner, W.P. Miller, M.P.W. Farina, M.A. Pavan, and M.V. Fey. 1989. Use of gypsum on soils: a review. Advances in Soil Science 9:1-111.

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EXECUTIVE SUMMARY

Field studies were conducted for three years to evaluate the effects of phosphogypsum on the yield and quality of wheat cut for forage. Yield responses to added fertilizer sulfur are expected on deep sandy soils such as those found in the coastal plain region of the southeastern United States. These soils have a low capacity for retaining reserves of plant available sulfur. Past research has shown that sulfur fertilization of forages can increase livestock performance and the livestock carrying capacity of pastures. Pastures fertilized with sulfur tend to produce a more palatable and digestible forage. In Alabama and Florida there are more than eight million acres of forage crops (improved permanent pastures and annual forages) and phosphogypsum should be an excellent source of sulfur.

The studies were conducted on a Dothan fine sandy loam and a Benndale fine sandy loam located in south Alabama. Treatments included two methods of tillage, two nitrogen rates, five rates of sulfur and two times of sulfur application. Tillage treatments were 1) Conventional-turn and disk prior to planting and 2) Reduced-disk only prior to planting. The soil was turned with a moldboard plow at a depth of 20 to 25 cm. Disking was with an offset disk to a depth of 8 to 13 cm. Nitrogen rates were 134 and 202 kg per ha. Sulfur rates were 0, 11, 22, 45 and 90 kg per ha or 0, 1, 2, 4 and 8 phosphogypsum units per acre. The rates of

added sulfur corresponded to phosphogypsum rates (Table 2) of 0, 30, 59, 119 and 293 kg per ha, respectively. Times of sulfur application were 1) prior to planting (fall) and 2) top dressing in early February (spring). Sulfur was applied as phosphogypsum which contained 15.3% sulfur. Additional treatments were included where agricultural grade gypsum was applied at a single rate of 45 kg per ha.

Wheat was planted in October or November of each cropping year and harvested as needed for forage yields. Forage was subsampled by plot as needed for nitrogen, sulfur, forage quality and percentage leaves determinations. Soil samples from selected treatments were collected in the spring of each year after the final wheat harvest.

Wheat forage yields were affected by tillage during the third year of the study on the Benndale soil and during all three years of the study on the Dothan soil. During the third year of the study on the Benndale soil, average forage yields were 38% higher under conventional tillage as compared to the reduced tillage system. On the Dothan soil the conventional tillage system produced an average of 33.6% more forage as compared to the reduced tillage system. Root density and soil penetrometer measurements showed that lower yields under reduced tillage resulted from soil compaction

As expected, forage yields were increased with increasing rates of nitrogen. On the Benndale soil average forage yields were increased by an average of 13.3% by increasing the nitrogen rate from 134 to 202 kg per ha. When averaged over three years, the 180 pounds nitrogen per acre rate increased forage yields 18.6% as compared to the 134 kg nitrogen rate on the Dothan soil.

Wheat responded to the application of sulfur at both locations, but the greatest response was obtained on the Dothan soil. On the Benndale soil, three-year average yields were increased by 5.4% by the application of sulfur. Wheat forage yields on the Dothan soil were increased by an average of 9.3% by the application of sulfur. The greatest yield response was obtained at the second cutting during the second year of the study on the Dothan soil. Yields at this harvest were increased 34% by the applied sulfur. Response to the time of sulfur application was inconsistent and varied among sites. During the first two years of the study an average of 6% higher yields were obtained by applying sulfur in the spring to the Benndale soil. In contrast, an average of 8% higher yields were obtained during the second and third years of the study by applying sulfur in the fall. Results from both locations show that maximum forage yields were obtained when 22 to 45 kg of sulfur were applied per acre as phosphogypsum. Statistical analysis showed that there were no differences in forage yields between phosphogypsum and agricultural grade gypsum when applied at a rate of 45 kg of sulfur per acre. Yield responses to added sulfur were generally greater under reduced tillage as compared to the conventional tillage system, however, tillage effects were not completely eliminated by applying higher rates of sulfur.

Nitrogen concentration in harvested wheat was increased by the rate of nitrogen and the concentration of sulfur was increased by added sulfur. Nitrogen:sulfur ratios tended to decrease with increasing rates of phosphogypsum indicating that a higher quality forage was being produced. Based on nitrogen:sulfur ratios, in some instances a higher quality forage was being produced at the 45 and 90 kg per ha sulfur rates although wheat yields leveled off at 22 to 45 kg of sulfur per ha. During the second year of the study, crude and digestible protein were increased in forage from the second cutting on the Dothan soil by the application of sulfur. Percentage of leaves and stems in harvested wheat were not affected by any fertility treatments.

The phosphogypsum contained 21 pCi Radium-226 per gram and 8.1 pCi Polonium-210 per kilogram. Analysis of selected soil and forage samples showed that there were little if any effects of phosphogypsum on the levels of these isotopes in either the soil or harvested forage.

The application of phosphogypsum increased the level of extractable SO_4 in the subsoil at each location. Relative increases in extractable subsoil SO_4 suggest that most of the applied sulfur may have leached out of the rooting zone. The application of phosphogypsum resulted in a displacement of exchangeable magnesium in the surface 0 to 25 cm of soil.

Results of this three year field study show that yield increases in wheat forage can be expected by applying sulfur as phosphogypsum to deep sandy soils located in the coastal plain region of Alabama. Phosphogypsum was shown to be an acceptable source of fertilizer sulfur for annual forage production. Maximum yields were obtained at approximately 22 kg of sulfur per ha.

INTRODUCTION

Crop responses to applied sulfur are expected on deep sandy soils such as those found in the coastal plain region of the southeastern United States. Surface horizons of sandy coastal plain soils have low adsorption capacities for sulfate-sulfur and typically have low levels of extractable sulfate-sulfur (Mitchell and Blue, 1981; Neller, 1959; Rabuffetti and Kamprath, 1977; Reneau and Hawkins, 1980; Rhue and Kamprath, 1973). A small adsorption capacity for sulfate-sulfur will result in limited residual effects of applied sulfur if leaching is occurring (Rhue and Kamprath, 1973).

Yield responses to applied sulfur have been reported for row and forage crops grown in the Southeast (Jordan, 1964; Rabuffetti and Kamprath, 1977; Reneau and Hawkins, 1980; Jones et al., 1979; Mitchell and Blue, 1989; Suarez and Jones, 1982; Oates and Kamprath, 1985; Thompson and Neller, 1963; Woodhouse, 1969). Sulfur fertilization has been shown to increase forage yields by as much as 50% under sulfur limiting conditions (Walker et al., 1956; Rees et al., 1974; Jones et al., 1982). In New Zealand an annual application of 22 kg of sulfur per ha is needed for adequate pasture growth (Adams, 1973). The current recommendation for sulfur on all crops in Alabama is 11 kg per ha per year (Cope et al., 1983).

Research in the southeastern United States has shown that deep tillage is necessary to optimize wheat yields (Hargrove and Hardcastle, 1984, Karlan and Gooden, 1987; Sharpe et al., 1988; Touchton and Johnson, 1982). Root growth and distribution in many of these soils is restricted by traffic pans. Oates and Kamprath (1985) concluded that sulfur deficiency on wheat is likely to occur in soils that have a sandy surface layer and a tillage pan that restricts root growth into the subsoil.

Fertilizer sulfur will not only increase forage yields but will also improve livestock performance. Rendis and Weir (1959) observed improvements in lamb performance when lambs were fed alfalfa grown on a sulfur fertilized soil. Jones et al. (1982) reported that sulfur fertilization of subclover-grass and ryegrass pastures increased the average daily gains of lambs by approximately 50%. Feed efficiency was also improved by sulfur fertilization. Research in Ireland showed that sulfur fertilization increased cattle weight gains by 20% (Murphy et al., 1983). The stock carrying capacity of the pasture was increased 21%.

Improvements in stock performance by sulfur fertilization has been attributed to increased forage production, a more palatable forage and increased levels of sulfur in the forage. Sulfur fertilization increased the in vitro digestibility of alfalfa (Rendig and Weir, 1957). Jones et al. (1982) reported that sulfur fertilization increased ryegrass consumption by lambs and in vitro digestibility. Feeding sulfur fertilized pangola grass forage to sheep increased dry matter intake by

44% and increased dry matter digestibility by 9% (Rees et al., 1974). Hunter et al. (1978) reported that sulfur fertilization tripled the digestible dry matter intake of harvested hay by lambs. Forage digestibility was increased 73% by sulfur fertilization.

Sulfur and nitrogen are components of protein, and have been shown to be closely related in both plant and animal nutrition. In general, increases in sulfur levels will improve the protein quality of forages (Tisdale, 1977). Protein formation in young wheat, corn and bean plants has been shown to be reduced by the lack of sulfur (Steward and Porter, 1969). Adequate sulfur has been shown to increase nitrogen fixation in forage legumes (Walker et al., 1956) and increase nitrogen fixation use efficiency by corn (Rabuffetti and Kamprath, 1977). The ratio of nitrogen to sulfur (N:S ratio) has been used as an indicator of sulfur deficiency in plant production and animal feed. Maximum crop yields have been associated with N:S ratio in plant tissue ranging from 14:l to 19:l (Bull, 1971; Metson, 1973; Reneau and Hawkins, 1980; Stewart and Porter, 1969; Tisdale, 1977). Whereas ruminants require N:S ratio between 10:l and 12:l for optimum performance (Allaway and Thompson, 1966; Moir et al., 1967-1968; Murphy et al., 1983; Rendig and Weir, 1957; Tisdale, 1977). Thus it is possible that animal performance could be improved by sulfur fertilization of forage crops without affecting yields.

Increasing forage production and improving forage quality through sulfur fertilization would benefit the economy of both Alabama and Florida. Alabama has approximately 4.34 million acres of forage crops (Ball, 1984). In Florida there are 3 million acres of improved permanent pasture, one million acres of temporary forage and 9 million acres of native range and woodland pasture (IFAS, 1983). Thus, there exists a large potential for increasing fertilizer sulfur use and increasing forage and livestock production. Waste phosphogypsum generated in the production of wet process phosphoric acid is $\simeq$ 92 % calcium sulfate (FIPR, 1983) and should be an excellent source of sulfur and calcium for forage production in the southeast.

A series of field studies were conducted in south Alabama with the following objectives: 1) Determine influence of phosphogypsum on forage yield and quality, 2) Establish rate of phosphogypsum needed for optimum forage yield and quality, 3) Determine effects of tillage on yield and sulfur fertilizer requirements and 4) Determine if split sulfur applications (fall vs spring) will improve forage yield and quality.

MATERIALS AND METHODS

Field studies were initiated in the fall of 1986 on Benndale and Dothan soils. Both soils have sandy textures and are located in the coastal plain region of Alabama (Table 1).

Table 1. Initial chemical properties of the Dothan fine sandy loam and Benndale fine sandy loam soils receiving annual rates of phosphogypsum.

Location	Soil Series	Soil Depth	SO_4-S[#]	pH	Extractable Elements[&] Ca	K	Mg	P
		-- cm --	ppm		------ kg/ha			-------
Brewton	Benndale	0 to 25	6.1	6.2	713	65	81	67
Brewton	Benndale	25 to 51	16.3	5.2	280	52	63	5
Headland	Dothan	0 to 25	9.6	6.5	773	97	152	66
Headland	Dothan	25 to 51	14.5	5.8	325	45	64	3

[#] Extracted with a calcium phosphate solution.
[&] Extracted with Mehlich I (dilute double acid) extractant.

Treatments included two methods of tillage, two nitrogen rates, five rates of sulfur and two times of sulfur application. Tillage treatments were 1) turn-disk prior to planting and 2) disk only prior to planting. The soil was turned with a moldboard plow at a depth of 20 to 25 cm. Disking was with an offset disk to a depth of 8 to 13 cm. On the Dothan soil the entire experimental area received one pass with a field cultivator just prior to planting. Nitrogen rates were 134 and 202 kg per ha. Sulfur rates were 0, 11, 22, 45, and 90 kg per ha (0, 1, 2, 4 and 8 phosphogypsum units per acre). The rates of added sulfur corresponded to phosphogypsum rates (Table 2) of 0, 30, 59, 119 and 293 kg per ha, respectively. Times of Sulfur application were 1) prior to planting (fall) and 2) top dressing in early February (spring). Sulfur was applied as phosphogypsum. Additional treatments were included where Agricultural grade gypsum (Gold Bond Gypsum) was applied at a single rate of 45 kg sulfur per ha. The fall applications of S were made prior to the final disking operation. These treatments allowed the comparison of the performance of phosphogypsum with agricultural grade gypsum. The experiment was a split plot design with 4 replications. Tillage methods were the whole plots. Nitrogen rates, sulfur rates and time of sulfur application were the split-plots. Split-plots were arranged as a randomized complete block within a tillage system.

Phosphogypsum was obtained from the Mississippi Chemical Company fertilizer plant located in Pascagoula, Mississippi. Approximately one ton of material was collected and stockpiled for use in this three year project. Chemical analysis data for the phosphogypsum and the agricultural grade gypsum are given in Table 2. The phosphogypsum contained 15.3% sulfur on a dry weight basis and 12.4% sulfur on a wet weight basis (19.7% water).

Table 2. Composition of the phosphogypsum and agricultural gypsum applied as a source of S for wheat. Element concentrations are given on an oven dry weight basis.

Source	S	Al	Ca	F	Fe	K	Mg	Na	P	Si
	%									
Phosphogypsum*	15.3	0.12	20.8	0.98	0.14	1.61	0.01	0.12	0.65	3.58
Agric-gypsum@	15.7	1.03	20.6	0.03	0.37	0.26	0.63	0.24	0.01	0.71

* The phosphogypsum contained 21 pCi Ra-226 per gram and 8.1 pCi Po-210 per kilogram.
@ The agricultural gypsum contained 0.18 pCi Ra-226.

Experimental areas were treated with limestone, potassium and phosphorus according to soil test. Wheat was planted in October or November each year. 'Compton' wheat was planted at both locations in 1986-1987 and 'Mcnair 1003' wheat was planted in 1987-1988 and 1988-1989. The fall applications of sulfur and half of the nitrogen were broadcast prior to planting. Spring applications of sulfur and the remaining nitrogen were broadcast in February. Sulfur was applied as phosphogypsum (15.3 % sulfur) which is a by-product of the phosphate fertilizer industry. Wheat forage yields were determined by harvesting a strip in each plot as needed. Except for the first year (1986-1987) on the Benndale soil, three forage harvests were taken per year. A summer forage crop was grown at each location to evaluate the residual effects of treatments applied during the previous wheat cropping year. Sorghum-sudangrass was grown at Brewton and Pearl Millet at Headland. The summer forage crop was harvested one time at each location for yield.

Forage subsamples were saved by plot from each harvest and ground. Prior to grinding wheat forage from the final harvest in 1987 and 1988 a subsample from each plot was separated into leaves and stems to determine the percentage leaves. Selected forage samples were analyzed for nitrogen using a LECO corporation, Carbon-Hydrogen-Nitrogen determinator. Sulfur was analyzed using a LECO Corporation Sulfur Determinator. Selected forage samples were analyzed for several forage quality parameters. Forage from selected harvests and selected treatments was also analyzed for Radium-226 and Polonium-210. These analyses were conducted under a sub-contract by Post, Buckley, Schuh & Jernigan, Inc. (Environmental Laboratories, Orlando Florida).

Soil samples were collected in the spring of 1987 and 1988 from selected treatments at depths of 0 to 15, 15 to 30 and 30 to 46 cm. At the end of the study in 1989 a more intensive sampling was conducted and soil was collected at depths of 0 to 25, 25 to 51, 51 to 76 and 76 to 102 cm. All samples were analyzed according to soil test procedures (Hue and Evans, 1986) for pH and extractable Ca, K, Mg and P. The soil samples were also extracted for SO_4 analysis using a calcium phosphate solution. In the spring of 1987 soil cores were collected from selected treatments at depths of 0 to 20 and 20 to 30 cm. Roots were collected by washing, and root length was determined using the line intersect method (Tennant, 1975).

RESULTS AND DISCUSSION

Forage Yields - Wheat

Brewton. A late planting date resulted in slow early season growth of wheat on the Benndale fine sandy loam soil and this resulted in only one forage harvest during the 1986-1987 growing season. During the second and third year of the study three forage harvests were taken. Forage yields from the Benndale soil are summarized in Tables 3 - 5. Yields in 1986-1987 and in 1987-1988 were affected by N rate, S rate and time of S application ($P \leq 0.10$). During the first two years of the study the conventional tillage system averaged 13.8% higher yields then the reduced tillage system when yields were averaged over all sulfur and nitrogen rates. However, differences due to tillage were not statistically significant. In 1986-1987 (Table 3) yields were increased by as much-as 13% by the application of sulfur. Applying sulfur in the spring increased forage yields by an average of 8% over the fall application. similar trends were observed in 1987-1988 (Table 4). In 1988-1989 (Table 5) yields for each cutting and total yields were affected by tillage and the rate of nitrogen ($P \leq 0.05$). Sulfur affected yields only for the second cutting ($P \leq 0.05$). As expected, forage yields increased as the nitrogen rate was increased from 134 to 202 kg per ha during all three years of the study (Tables 3 - 5). The 202 kg per ha nitrogen rate produced an

Table 3. Effect of phosphogypsum (sulfur rate), time of phosphogypsum application, tillage and nitrogen on wheat forage yields in 1986-1987 on a Benndale fine sandy loam soil.

Trt. No.	Nitrogen Rate	Sulfur Rate	Time of S Application	Wheat Forage Yield Conv*	Reduced
	---- kg/ha -----			-kg dry matter/ha-	
1	134	0	Fall	2481.1	2056.6
2	134	0	Spring	2288.3	2269.7
5	134	11	Fall	2861.2	2125.4
6	134	11	Spring	3074.8	2757.6
9	134	22	Fall	2525.4	2274.1
10	134	22	Spring	3066.9	2344.4
13	134	45	Fall	3136.8	2292.8
14	134	45	Spring	3238.9	2787.4
17	134	90	Fall	2667.3	2474.6
18	134	90	Spring	3214.2	2970.1
3	202	0	Fall	2979.3	2429.5
4	202	0	Spring	2908.6	2334.5
7	202	11	Fall	2910.0	2663.7
8	202	11	Spring	3057.2	3183.8
11	202	22	Fall	3145.5	2766.7
12	202	22	Spring	2907.3	2843.9
15	202	45	Fall	3129.3	2808.7
16	202	45	Spring	3379.5	2967.3
19	202	90	Fall	2742.3	2849.7
20	202	90	Spring	3305.3	2825.8

LSD(0.05) - Sulfur Rate = 246 kg/ha.
LSD(0.05) = Nitrogen Rate = 156 kg/ha.

* Conventional refers to conventional tillage -- turning with a moldboard plow and disking prior to planting. Reduced refers to reduced tillage -- disking the area prior to planting.

Table 4. Effect of phosphogypsum (sulfur rate), tillage and nitrogen on wheat forage yields in 1987-1988 on a Benndale fine sandy loam soil.

Tillage	Nitrogen Rate	Sulfur Rate, kg/ha 0	11	22	45	90
	kg/ha	------ kg dry matter/hectare -------				
First Cut, 1/15/88						
Conv[@]	134	1162	913	1029	1108	1082
Conv	202	1292	1190	1128	1040	1244
Reduced	134	917	896	786	803	922
Reduced	202	1088	1183	1146	1060	1059
LSD(0.05) - Nitrogen Rate = 97 kg/ha.						
Second Cut, 2/24/88						
Conv	134	373	311	256	286	245
Conv	202	381	284	321	298	432
Reduced	134	200	216	224	207	234
Reduced	202	280	295	306	252	264
LSD(0.05) - Tillage X Nitrogen X Sulfur = 77 kg/ha.						
Third Cut, 4/21/88						
Conv	134	3387	3773	3705	3756	3792
Conv	202	3551	3927	4135	4357	3952
Reduced	134	2864	3239	3333	3417	3333
Reduced	202	3027	3453	3764	3890	3591
LSD(0.05) - Sulfur Rate = 208 kg/ha.						
LSD(0.05) - Nitrogen Rate = 131 kg/ha.						
Total, 1988						
Conv	134	4922	4997	4989	5150	5119
Conv	202	5224	5515	5584	5757	5628
Reduced	134	3981	4351	4343	4627	5628
Reduced	202	4396	4931	5216	5201	4914
LSD(0.05) - Sulfur Rate = 298 kg/ha.						
LSD(0.05) - Nitrogen Rate = 189 kg/ha.						

[@] Conv refers to conventional tillage -- turning with a moldboard plow and disking prior to planting. Reduced refers to reduced tillage -- disking the area prior to planting.

Table 5. Effect of phosphogypsum rate (sulfur rate), tillage and nitrogen on wheat forage yields (1988-1989) on a Benndale fine sandy loam soil.

Tillage	Nitrogen Rate	Sulfur rate, kg/ha 0	11	22	45	90
	kg/ha	kg/ha				
First Cut, 11-29-88						
Conv*	134	843	879	896	887	886
Conv	202	925	1059	1010	997	940
Reduced	134	512	455	436	427	474
Reduced	202	555	602	647	607	547
LSD(0.05)	- Nitrogen rate = 49 kg/ha.					
LSD(0.05)	- Tillage = 121 kg/ha.					
Second Cut, 2-9-89						
Conv	134	916	788	798	765	795
Conv	202	1202	1163	1175	1153	1019
Reduced	134	608	489	399	479	506
Reduced	202	821	836	762	746	633
LSD(0.05)	- Sulfur rate = 90 kg/ha.					
LSD(0.10)	- Nitrogen rate = 68 kg/ha.					
LSD(0.05)	- Tillage = 230 kg/ha.					
Third Cut, 4-11-89						
Conv	134	2349	2754	2576	2644	2837
Conv	202	2630	2904	2863	2897	2747
Reduced	134	2146	2053	1821	2079	2184
Reduced	202	2467	2408	2311	2348	2157
LSD(0.05)	- Nitrogen rate = 115 kg/ha.					
LSD(0.05)	- Tillage x Sulfur rate = 182 kg/ha.					
Total Yields						
Conv	134	4108	4421	4271	4296	4518
Conv	202	4756	5126	5048	5048	4716
Reduced	134	3266	2997	2656	2985	3165
Reduced	202	3842	3846	3720	3701	3337
LSD(0.05)	- Nitrogen rate = 181 kg/ha.					
LSD(0.05)	- Tillage = 450 kg/ha.					

average of 13.3% higher yields during the three years of the study as compared to the 134 kg per ha rate. In 1988-1989, the conventional tillage system (4631 kg/ha) out-yielded the reduced tillage system (3352 kg/ha) by 38% when the yields are averaged over all other factors.

Headland. Wheat forage yields on the Dothan fine sandy loam are presented in Tables 6 - 9. In all three years of the study higher yields were obtained under conventional tillage ($P \leq 0.10$). The conventional tillage system produced an average of 33.6% more forage as compared to the reduced tillage system. Except for the first cutting in 1989, forage yields at each harvest and total forage yields were affected by the rate of nitrogen ($P \leq 0.05$). When averaged over the three years, the 202 kg nitrogen per ha rate produced 18.6% higher forage yields as compared to the 134 kg nitrogen rate.

In 1986 -1987, the second cutting, third cutting and total yields were affected by the rate of sulfur ($P \leq 0.05$). Total forage yields and yields at the second cutting in 1987-1988 and 1988-1989 were affected by the rate of sulfur ($P \leq 0.05$). In 1986-1987 no response was obtained to the time of sulfur application, whereas in the remaining two years higher yields were obtained when sulfur was applied in the fall ($P \leq 0.05$). An exception are yields at 45 and 90 kg sulfur rates under conventional tillage in 1988-1989 (Table 9). For the last two years of the study, fall applications of sulfur increased total forage yields by an average of 8%. The

Table 6. Effect of phosphogypsum (sulfur rate), tillage, and nitrogen on wheat forage yields in 1986-1987 on a Dothan fine sandy loam soil.

Nitrogen Tillage	Sulfur Rate	Rate	Yield of Harvested Forage First Cut	Second	Third	Total
	--kg/ha	--	--------	kg dry matter/ha		--------
Conv*	134	0	663.4	723.8	1284.5	2671.8
Conv	134	11	644.9	821.7	1702.7	3169.2
Conv	134	22	713.5	815.2	1399.3	2927.9
Conv	134	45	779.2	909.1	1627.4	3315.6
Conv	134	90	629.5	879.1	1668.2	3176.8
Conv	202	0	1038.5	1173.8	1933.6	4145.9
Conv	202	11	853.5	1243.4	1865.7	3962.6
Conv	202	22	806.0	914.5	1700.0	3420.5
Conv	202	45	811.8	1239.3	2060.9	4112.0
Conv	202	90	890.0	1296.3	2032.7	4219.0
Reduced	134	0	580.0	559.5	1248.8	2388.3
Reduced	134	11	439.4	630.7	1284.8	2354.8
Reduced	134	22	534.0	618.8	1232.1	2384.8
Reduced	134	45	512.8	655.5	1602.8	2771.2
Reduced	134	90	494.1	810.3	1434.7	2739.1
Reduced	202	0	591.0	729.1	1502.9	2823.0
Reduced	202	11	556.0	934.4	1780.2	3270.6
Reduced	202	22	538.8	867.4	1883.9	3290.1
Reduced	202	45	596.2	929.3	1868.5	3393.9
Reduced	202	90	535.7	957.3	1869.9	3362.9
Significant effects						
Sulfur Rate			NS@	93	200	283
Nitrogen Rate			NS	NS	126	179
Tillage			NS	NS	202	194
Tillage X Nitrogen Rate			99#	83	NS	NS

* Conv refers to conventional tillage -- turning with a moldboard plow and disking prior to planting. Reduced refers to reduced tillage -- disking the area prior to planting.

@ NS = Nonsignificant. Numbers = LSD(0.05) except where noted.

\# Interaction LSD(0.10).

Table 7. Effect of phosphogypsum (sulfur rate), tillage and nitrogen on wheat forage yields in 1987-1988 on a Dothan fine sandy loam soil.

Tillage	Nitrogen Rate	Sulfur Rate, kg/ha 0	11	22	45	90
	kg/ha	-------- kg dry matter/ha				--------
First Cut, 1/28/88						
Conv[@]	134	903	842	890	966	873
Conv	202	801	1182	1094	956	1048
Reduced	134	541	591	762	747	576
Reduced	202	759	757	808	808	669
LSD(0.05) - Nitrogen Rate = 81 kg/ha.						
LSD(0.01) - Tillage = 230 kg/ha.						
Second Cut, 3/14/88						
Conv	134	920	1123	1156	1278	1214
Conv	202	1185	1461	1436	1522	1450
Reduced	134	671	1121	931	948	912
Reduced	202	884	1142	1171	1227	1252
LSD(0.05) - Sulfur Rate = 106 kg/ha.						
LSD(0.05) - Nitrogen Rate = 67 kg/ha.						
LSD(0.10) - Tillage = 243 kg/ha.						
Third Cut, 4/21/88						
Conv	134	947	815	945	934	902
Conv	202	1054	1010	937	960	1207
Reduced	134	637	602	643	574	609
Reduced	202	737	823	702	757	733
LSD(0.05) - Nitrogen Rate = 59 kg/ha.						
LSD(0.05) - Tillage = 170 kg/ha.						
Total, 1988						
Conv	134	2770	2781	2991	3179	2990
Conv	202	3039	3653	3468	3437	3705
Reduced	134	1849	2314	2335	2269	2097
Reduced	202	2421	2725	2630	2793	2654
LSD(0.05) - Sulfur Rate = 215 kg/ha.						
LSD(0.05) - Nitrogen Rate = 136 kg/ha.						
LSD(0.10) - Tillage = 632 kg/ha.						

[@] Conv refers to conventional tillage. Reduced refers to reduced tillage.

Table 8. Effect of phosphogypsum rate (sulfur rate), tillage and nitrogen rate on wheat forage yields (1988-1989) on a Dothan fine sandy loam soil.

Tillage	Nitrogen Rate	Sulfur rate, kg/ha 0	11	22	45	90
	kg/ha			kg/ha		
		First Cut, 12-6-88				
Conv*	134	1579	1695	1837	1669	1700
Conv	202	1498	1985	1706	1988	1647
Reduced	134	988	1015	1071	1185	1066
Reduced	202	935	1134	1057	1228	1098
LSD(0.05) - Tillage x Sulfur rate = 209 kg/ha.						
		Second Cut, 1-26-89				
Conv	134	1259	1365	1354	1313	1277
Conv	202	1552	1623	1491	1611	1652
Reduced	134	860	873	965	1071	875
Reduced	202	930	997	1101	1144	1088
LSD(0.05) - Nitrogen rate = 93 kg/ha.						
LSD(0.05) - Tillage = 157 kg/ha.						
		Third Cut, 4-28-89				
Conv	134	1366	1403	1528	1609	1494
Conv	202	1716	1470	1640	1624	1519
Reduced	134	1116	1071	1051	1177	1134
Reduced	202	1145	1271	1549	1147	1342
LSD(0.05) - Nitrogen rate = 91 kg/ha.						
LSD(0.05) - Tillage = 99 kg/ha.						

Table 9. Effect of phosphogypsum rate (sulfur rate), time of phosphogypsum application, tillage and nitrogen rate on total wheat forage yields (1988-1989) on a Dothan fine sandy loam soil.

		Sulfur Rate, kg/ha									
	Nitrogen	0		11		22		45		90	
Tillage	Rate	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
	kg/ha	kg/ha									
Conv	134	4133	4276	4595	4331	4672	4766	4589	4595	4485	4457
Conv	202	4660	4872	5392	4764	4942	4733	5060	5386	5030	4607
Reduced	134	3114	2814	3306	2611	3111	3065	3680	3184	3227	2874
Reduced	202	3196	2826	3380	3425	4306	3109	4076	2961	3971	3085

LSD(0.05) - Sulfur rate = 285 kg/ha.
LSD(0.05) - Nitrogen rate = 180 kg/ha.
LSD(0.05) - Tillage x Time = 255 kg/ha.

application of sulfur increased forage yields by an average of 6.2%, 14.2% and 8.6% during the first, second and third year of the study, respectively. the greatest response to added sulfur occurred at the second cutting in 1987-1988 (Table 7). Forage yields at the second cutting were increased by an average of 41.5% by the application of sulfur under the reduced tillage system whereas in the conventional tillage system yields were increased by an average of 26.4% (Table 7). Yield responses to added sulfur were generally greater under reduced as compared to the conventional tillage system, however, tillage effects were not completely eliminated by applying higher rates of sulfur. Results from both locations show that maximum forage yields were obtained when 22 to 45 kg of sulfur were applied per ha as phosphogypsum.

Type of Gypsum. Phosphogypsum and a commercial Agricultural grade gypsum were applied at a rate of 45 kg per ha to determine if the type of gypsum would affect yields. During all three years of the study at both locations (Table 10) the two types of gypsum produced essentially the same forage yields ($P \leq 0.05$). This shows that phosphogypsum is just as effective as commercial fertilizer gypsum.

Table 10. Effect of phosphogypsum and Agricultural grade gypsum on total wheat forage yields when applied at a rate of 45 kg of sulfur per ha.

Soil	Year	Type of Gypsum	
		Phosphogypsum	Agricultural
		---------- kg/ha	-----------
Benndale	1986 - 1987	2827	2968
	1987 - 1988	5134	5036
	1988 - 1989	4008	3933
Dothan	1986 - 1987	3398	3233
	1987 - 1988	2920	2929
	1988 - 1989	4191	4025
	$\overline{X}$	3746	3687

LSD(0.05) = Nonsignificant

Forage Yields-Summer Cover Crop

A temporary summer forage crop was grown at each location to evaluate the residual effects of phosphogypsum treatments. Yields of summer forage at both locations in the summer of 1987 and 1988 are given in Tables 11 and 12, respectively. In 1987, summer forage yields were not affected by the residual effects of nitrogen or sulfur applied in the fall of 1986 and in the spring of 1987. Likewise, summer forage yields in 1988 were not affected by the residual effects of nitrogen or sulfur applied in the fall of 1987 or the spring of 1988. In 1988, higher summer forage yields were obtained under the reduced tillage system on the Dothan soil ($P \leq 0.05$).

Table 11. Effect of residual phosphogypsum and secondary treatments on yield of summer forage grown following wheat in 1987.

Tillage	Nitrogen Rate	Sulfur Rate	Headland Millet	Headland S	Brewton Sudangrass
	---- kg/ha ----		kg/ha	- % -	-- kg/ha --
Conv[@]	134	0	2700	0.12	1528
Conv	134	11	2369	0.12	1354
Conv	134	22	2302	0.13	1399
Conv	134	45	3555	0.13	1487
Conv	134	90	2723	0.14	1443
Conv	202	0	3125	0.12	1573
Conv	202	11	2943	0.13	1253
Conv	202	22	2374	0.12	1214
Conv	202	45	2386	0.14	1421
Conv	202	90	3237	0.13	1405
Reduced	134	0	2872	0.12	1251
Reduced	134	11	2580	0.11	1310
Reduced	134	22	3339	0.11	1149
Reduced	134	45	2927	0.13	1289
Reduced	134	90	2929	0.13	1299
Reduced	202	0	2644	0.11	1186
Reduced	202	11	2979	0.11	1346
Reduced	202	22	2788	0.12	1220
Reduced	202	45	2768	0.13	1309
Reduced	202	90	2593	0.13	1371
Significant effects					
Sulfur Rate			--	0.01	NS
Sulfur X Nitrogen Rate			485[#]	NS	NS

[@] Conv refers to conventional tillage -- turning with a moldboard plow and disking prior to planting. Reduced refers to reduced tillage -- disking the area prior to planting.

[#] Numbers = LSD(0.05). NS = Nonsignificant.

Table 12. Dry matter yields and S concentrations in summer forage crops in 1988 as affected by the residual effects of phosphogypsum, tillage and nitrogen treatments applied in 1987-1988.

Tillage	Nitrogen Rate	Sulfur Rate	Headland Millet	Headland S	Brewton Sudangrass	Brewton S
	----- kg/ha -----		kg/ha	- % -	- kg/ha -	- % -
Conv	134	0	5388	0.14	1032	0.08
Conv	134	11	5274	0.14	1262	0.08
Conv	134	22	5526	0.14	1122	0.08
Conv	134	45	5722	0.15	1262	0.09
Conv	134	90	5299	0.15	1150	0.08
Conv	202	0	5443	0.13	1212	0.09
Conv	202	11	5354	0.14	1170	0.08
Conv	202	22	5593	0.14	1045	0.08
Conv	202	45	5397	0.13	1364	0.08
Conv	202	90	5452	0.15	1115	0.09
Reduced	134	0	3553	0.11	973	0.08
Reduced	134	11	3743	0.11	987	0.09
Reduced	134	22	3927	0.11	1081	0.09
Reduced	134	45	4147	0.11	1069	0.08
Reduced	134	90	4049	0.13	1166	0.09
Reduced	202	0	3608	0.11	1236	0.08
Reduced	202	12	4012	0.12	890	0.08
Reduced	202	22	4006	0.11	1062	0.08
Reduced	202	45	3774	0.12	996	0.09
Reduced	202	90	3847	0.12	1003	0.09
Significant effects						
Sulfur Rate			NS[@]	0.01	NS	NS
Nitrogen Rate			NS	NS	NS	NS
Tillage X Sulfur Rate			NS	NS	174	NS

@ NS = Nonsignificant. Numbers = LSD (0.05).

Forage Analysis -

Nitrogen and Sulfur. Nitrogen and sulfur concentration data are summarized in Tables 13 - 16. Nitrogen concentration in wheat forage was increased at all harvests by the rate of added nitrogen. Likewise sulfur in the harvested forage increased with increased rates of added phosphogypsum. Except for the second harvest on the Dothan soil in 1987-1988, higher sulfur concentrations were obtained ($P \leq 0.05$) by applying sulfur in the fall (Tables 15 and 16). The nitrogen:sulfur ratio tended to decrease with increasing rates of phosphogypsum indicating that a higher quality forage is being produced. In several cases applying 45 to 90 kg sulfur per ha was still not high enough to reduce the N:S ratio into the range of 10:l to 12:l that is considered optimum for ruminant performance. During this three year study maximum forage yields were obtained at 22 to 45 kg sulfur per ha (Tables 3 - 9).

Analysis of the summer forage for sulfur (Tables 11 and 12) showed that in 1988 the concentration of sulfur in sorghum-sudangrass from the Benndale soil was not affected by residual treatments. On the Dothan soil, sulfur concentration in pearl millet was increased ($P \leq 0.10$) by the residual sulfur treatments in 1987 and 1988 (Tables 11 and 12).

Leaf Percentage. Leaf percentage was determined by plot at the final forage harvest in 1987 (Tables 13 and 14) and in

Table 13. Effect of phosphogypsum (sulfur rate) and secondary treatments on leaf analysis data for wheat forage grown on a Benndale fine sandy loam soil in 1986-1987.

Tillage	Nitrogen Rate	Sulfur Rate	N	S	N/S*	Leaves
	---- kg/ha ----		---- % ----			- % -
Conv[@]	134	0	1.95	0.11	17.9	52
Conv	134	11	1.77	0.14	14.1	48
Conv	134	22	1.77	0.14	13.2	50
Conv	134	45	1.78	0.15	13.0	50
Conv	134	90	1.73	0.17	10.7	51
Conv	202	0	2.35	0.12	20.6	51
Conv	202	11	2.20	0.15	15.8	47
Conv	202	22	2.07	0.16	13.7	51
Conv	202	45	1.95	0.18	11.3	46
Conv	202	90	2.07	0.19	11.2	54
Reduced	134	0	1.81	0.10	18.9	50
Reduced	134	11	1.64	0.12	14.9	44
Reduced	134	22	1.60	0.11	16.0	48
Reduced	134	45	1.60	0.13	12.2	46
Reduced	134	90	1.44	0.15	10.4	48
Reduced	202	0	2.26	0.12	19.4	48
Reduced	202	11	1.97	0.13	15.6	50
Reduced	202	22	1.91	0.13	15.8	50
Reduced	202	45	1.87	0.16	12.9	52
Reduced	202	90	2.00	0.19	10.9	47
Significant effects						
Sulfur Rate			0.11[#]	0.01	1.7	NS
Nitrogen Rate			NS	0.01	NS	NS

@ Conv refers to conventional tillage -- turning with a moldboard plow and disking prior to planting. Reduced refers to reduced tillage -- disking the area prior to planting.

Numbers = LSD(0.05). NS = Nonsignificant.

Table 14. Effect of phosphogypsum (sulfur rate) and secondary treatments on leaf analysis data for wheat forage grown on a Dothan Fine sandy Loam soil in 1986-1987.

Tillage	Nitrogen Rate	Sulfur Rate	First Cut N	First Cut S	First Cut N/S*	Second Cut N	Second Cut S	Second Cut N/S	Third Cut N	Third Cut S	Third Cut N/S	Leaves$
	---- kg/ha ----		--- % ---			--- % ---			--- % ---			- % -
Conv[a]	134	0	1.64	0.10	15.7	2.96	0.14	21.7	2.08	0.13	16.5	52
Conv	134	11	1.58	0.10	15.5	3.20	0.18	18.9	2.08	0.14	15.8	50
Conv	134	22	1.52	0.11	14.3	3.18	0.20	17.0	1.87	0.14	13.6	51
Conv	134	45	1.65	0.11	14.6	3.27	0.21	16.5	1.92	0.15	13.7	47
Conv	134	90	1.58	0.11	14.2	3.37	0.24	15.0	2.00	0.16	12.5	54
Conv	202	0	1.68	0.11	15.8	3.62	0.18	20.7	2.46	0.14	17.9	54
Conv	202	11	1.72	0.11	16.2	3.58	0.20	18.7	2.32	0.16	14.9	54
Conv	202	22	1.63	0.11	15.4	3.57	0.19	20.3	2.25	0.16	14.4	55
Conv	202	45	1.71	0.12	14.2	3.77	0.26	15.6	2.46	0.20	12.4	53
Conv	202	90	1.74	0.13	13.6	3.77	0.28	15.0	2.20	0.20	12.1	57
Reduced	134	0	1.51	0.10	14.7	3.16	0.13	24.3	2.21	0.14	15.8	56
Reduced	134	11	1.56	0.10	15.2	3.11	0.18	17.4	2.03	0.15	14.2	59
Reduced	134	22	1.37	0.10	13.8	3.19	0.18	18.4	2.00	0.14	14.7	54
Reduced	134	45	1.45	0.10	14.6	3.26	0.18	18.6	2.06	0.15	14.1	56
Reduced	134	90	1.56	0.11	14.2	3.09	0.22	14.4	1.95	0.18	11.1	53
Reduced	202	0	1.51	0.10	14.9	3.45	0.17	20.6	2.33	0.15	16.3	58
Reduced	202	10	1.60	0.11	15.3	3.83	0.20	19.6	2.28	0.16	14.6	56
Reduced	202	20	1.67	0.11	14.8	3.74	0.21	18.0	2.24	0.15	15.1	62
Reduced	202	40	1.60	0.12	13.6	3.64	0.24	16.7	2.06	0.19	11.6	56
Reduced	202	80	1.60	0.12	13.4	3.73	0.22	18.6	2.02	0.26	9.2	57
Significant effects												
Sulfur Rate			0.07[#]	0.007	--	NS	0.02	--	0.12	0.02	NS	NS
Nitrogen Rate			NS	0.01	--	0.09	0.01	--	0.08	0.01	NS	NS
Sulfur X Nitrogen Rate			NS	NS	0.9	NS	NS	2.1	NS	NS	NS	NS

* Nitrogen:Sulfur ratio.

@ Conv refers to conventional tillage -- turning with a moldboard plow and disking prior to planting. Reduced refers to reduced tillage -- disking the area prior to planting.

$ Percent leaves in the forage harvested at the third cutting.

Numbers = LSD(0.05). NS = Nonsignificant.

Table 15. Effect of phosphogypsum rate (sulfur rate), time of phosphogypsum application, tillage and nitrogen rate on nitrogen and sulfur concentrations and nitrogen, sulfur ratios in wheat forage from selected harvests (1987-1989) on a Benndale fine sandy loam soil.

			Fall Application of S									Spring Application of S								
	Nitrogen	Sulfur	First-1987-88			Second-1987-88			First-1988-89			First-1987-88			Second-1987-88			First-1988-89		
Tillage	Rate	Rate	N	S	N/S[@]	N	S	N/S	N	S	N/S	N	S	N/S	N	S	N/S	N	S	N/S
	--- kg/ha --		--- % ---			--- % ---			--- % ---			--- % ---			--- % ---			--- % ---		
Conv[$]	134	0	1.83	0.15	12.9	1.88	0.16	11.8	2.67	0.17	15.2	1.89	0.15	13.1	1.77	0.14	13.1	2.61	0.17	15.3
Conv	134	11	1.78	0.15	12.5	1.76	0.15	12.0	2.81	0.21	13.5	1.76	0.14	12.8	1.70	0.12	14.3	2.76	0.19	15.4
Conv	134	22	1.80	0.15	12.1	1.73	0.15	11.9	2.68	0.23	11.5	1.73	0.47	9.3	1.80	0.13	14.5	2.61	0.17	15.1
Conv	134	45	1.67	0.18	9.5	1.81	0.17	11.0	2.84	0.28	10.4	1.77	0.17	10.4	1.76	0.16	11.3	2.73	0.18	15.0
Conv	134	90	1.73	0.23	7.8	1.66	0.16	10.5	2.70	0.27	10.1	1.76	0.15	12.5	1.76	0.14	12.5	2.98	0.18	16.8
Conv	202	0	1.91	0.16	12.5	1.78	0.13	14.6	3.09	0.17	19.3	2.17	0.15	14.3	1.84	0.14	13.4	3.11	0.19	16.5
Conv	202	11	2.00	0.19	10.8	1.82	0.16	11.9	3.14	0.24	13.4	1.87	0.16	12.1	1.65	0.13	13.3	2.92	0.17	17.5
Conv	202	22	2.01	0.17	13.0	1.94	0.17	11.5	3.22	0.27	12.1	1.91	0.16	12.3	1.74	0.14	12.4	2.92	0.17	17.3
Conv	202	45	1.85	0.18	9.6	1.84	0.17	11.1	3.17	0.26	13.3	2.07	0.15	13.9	1.81	0.14	12.7	2.78	0.19	15.3
Conv	202	90	1.98	0.19	10.8	1.87	0.19	10.2	2.82	0.29	10.0	2.03	0.13	16.9	1.82	0.14	13.1	3.04	0.19	15.7
Reduced	134	0	1.59	0.13	12.5	1.78	0.13	14.2	2.25	0.16	14.2	1.74	0.14	12.7	1.74	0.14	13.1	2.51	0.17	15.1
Reduced	134	11	1.63	0.16	10.5	1.76	0.12	14.5	2.16	0.18	12.0	1.73	0.14	12.9	1.69	0.13	13.6	2.16	0.17	14.4
Reduced	134	22	1.65	0.14	11.8	1.54	0.12	13.1	2.03	0.18	11.4	1.64	0.14	11.5	1.62	0.13	12.6	2.23	0.16	14.3
Reduced	134	45	1.64	0.17	10.1	1.76	0.15	12.0	2.26	0.21	11.1	1.72	0.13	13.1	1.77	0.14	12.5	2.43	0.17	14.2
Reduced	134	90	1.61	0.17	9.5	1.68	0.17	10.0	2.45	0.28	9.0	1.61	0.14	12.0	1.73	0.14	13.1	2.36	0.17	14.2
Reduced	202	0	1.91	0.13	15.0	1.84	0.15	13.9	2.67	0.17	15.4	1.97	0.14	14.3	1.87	0.14	13.9	2.62	0.16	16.8
Reduced	202	11	1.84	0.16	11.7	1.68	0.11	16.3	2.51	0.17	15.0	1.87	0.13	14.3	1.87	0.14	13.1	2.76	0.17	16.4
Reduced	202	22	1.76	0.17	10.3	1.69	0.13	13.1	2.56	0.20	12.8	1.98	0.13	15.0	1.74	0.13	13.9	2.53	0.17	14.9
Reduced	202	45	1.78	0.17	10.7	1.65	0.15	11.1	2.42	0.23	10.6	1.91	0.14	14.2	1.83	0.14	12.9	2.81	0.17	16.6
Reduced	202	90	1.76	0.18	10.1	1.87	0.17	11.5	2.17	0.26	8.3	1.85	0.14	13.8	1.59	0.12	13.3	2.62	0.16	15.7

Significant effects

First-1987-88: Nitrogen Concentration - N rate - LSD(0.05) = 0.05%; N/S ratio - S Rate X Time - LSD(0.05) = 1.4.

Second-1987-88: Nitrogen Concentration - N rate - LSD(0.05) = 0.04%;
Sulfur Concentration - S Rate x Time - LSD(0.05) = 0.01%.
N/S Ratio - Tillage X S Rate X Time - LSD(0.10) = 1.4.

First-1988-89: Nitrogen Concentration - Nitrogen rate - LSD(0.05) = 0.10% and Time - LSD(0.05) = 0.01%;
Sulfur Concentration - S Rate X Time - LSD(0.05) = 0.02% and Tillage - LSD(0.05) = 0.01%;
N/S ratio - N rate- LSD(0.05) = 0.7.

[#] Conv = conventional tillage. Reduced = Reduced tillage.

[@] N/S = nitrogen to sulfur ratio.

Table 16. Effect of phosphogypsum rate (sulfur rate), time of phosphogypsum application, tillage and nitrogen on nitrogen and sulfur concentrations and nitrogen, sulfur ratios in wheat forage from selected harvests (1987-1989) on a Dothan fine sandy loam soil.

			Fall Application of S									Spring Application of S								
	Nitrogen	Sulfur	First-1987-88			Second-1987-88			First-1988-89			First-1987-88			Second-1987-88			First-1988-89		
Tillage	Rate	Rate	N	S	N/S[@]	N	S	N/S	N	S	N/S	N	S	N/S	N	S	N/S	N	S	N/S
	-- lbs/acre --		--- % ---			--- % ---			--- % ---			--- % ---			--- % ---			--- % ---		
Conv[$]	134	0	2.00	0.15	15.3	2.74	0.16	18.4	2.75	0.13	21.1	2.26	0.15	15.8	2.62	0.13	19.8	2.7	0.15	18.6
Conv	134	11	2.17	0.15	14.9	2.86	0.14	21.3	2.95	0.19	15.2	2.04	0.14	14.8	2.18	0.15	19.1	2.8	0.14	19.9
Conv	134	22	1.99	0.15	13.3	2.76	0.14	19.8	2.99	0.20	14.7	2.13	0.14	15.4	3.04	0.19	16.2	2.6	0.14	18.2
Conv	134	45	2.02	0.18	10.8	2.83	0.16	17.9	2.95	0.22	13.5	2.25	0.17	13.2	3.10	0.20	17.3	2.7	0.15	18.3
Conv	134	90	2.24	0.23	9.87	3.04	0.17	17.9	2.79	0.22	12.5	1.98	0.15	13.7	2.73	0.23	11.8	2.7	0.14	19.0
Conv	202	0	2.14	0.16	13.7	2.97	0.16	19.9	2.93	0.14	20.8	2.33	0.15	15.4	2.88	0.14	20.8	2.8	0.14	19.8
Conv	202	12	2.26	0.19	12.2	3.06	0.17	18.0	3.22	0.20	15.8	2.42	0.16	15.6	3.31	0.19	17.8	2.8	0.15	19.1
Conv	202	22	2.34	0.17	14.1	3.25	0.19	17.3	3.31	0.20	16.4	2.37	0.16	15.3	3.33	0.22	15.5	2.9	0.15	19.0
Conv	202	45	2.29	0.18	12.7	3.07	0.15	23.9	3.25	0.23	14.5	2.28	0.15	15.0	3.17	0.19	16.7	2.9	0.15	19.5
Conv	202	90	2.07	0.19	11.0	3.31	0.19	17.5	3.26	0.23	14.4	2.08	0.13	17.3	3.09	0.26	13.8	3.2	0.15	21.8
Reduced	134	0	1.91	0.13	15.0	2.57	0.12	22.2	2.83	0.15	18.7	2.06	0.14	15.1	2.72	0.11	25.3	3.0	0.15	20.2
Reduced	134	11	1.97	0.16	12.8	2.75	0.14	19.3	3.06	0.19	15.8	1.88	0.14	13.8	2.80	0.14	20.0	2.9	0.14	20.6
Reduced	134	22	1.91	0.14	13.7	2.78	0.14	19.0	2.95	0.22	13.4	1.91	0.14	13.7	2.90	0.19	15.5	2.7	0.15	19.0
Reduced	134	45	2.11	0.17	13.1	2.89	0.18	16.5	3.10	0.24	13.0	2.08	0.13	15.7	2.88	0.19	16.3	3.0	0.15	19.7
Reduced	134	90	1.85	0.17	10.9	3.18	0.20	15.2	2.88	0.23	12.5	2.02	0.14	14.9	2.75	0.23	12.7	2.9	0.15	19.9
Reduced	202	0	2.24	0.13	17.5	2.72	0.11	24.2	2.86	0.13	21.5	2.22	0.14	16.1	2.69	0.12	22.5	2.9	0.14	19.8
Reduced	202	11	2.29	0.16	14.5	2.95	0.14	21.6	3.34	0.21	16.1	2.08	0.13	16.0	2.97	0.15	19.7	2.9	0.13	21.4
Reduced	202	22	2.01	0.17	11.7	3.02	0.16	19.4	3.40	0.22	15.4	2.25	0.13	17.1	3.14	0.18	18.5	3.0	0.15	19.0
Reduced	202	45	2.00	0.17	12.1	3.24	0.20	17.4	3.47	0.24	14.2	2.21	0.14	16.4	3.24	0.25	12.9	2.9	0.14	21.0
Reduced	202	90	1.97	0.18	11.3	3.48	0.19	17.0	3.33	0.25	13.5	2.02	0.14	15.0	2.97	0.27	11.4	2.9	0.15	19.6

Significant effects

First-1987-88: Nitrogen Concentration - LSD(0.10) = 0.23%
Sulfur Concentration - S rate X Time - LSD(0.05) = 0.01% and Tillage - LSD(0.05) = 0.01%.
N/S Ratio - LSD(0.10) = 1.96.

Second-1987-88: Nitrogen Concentration - N rate - LSD(0.05) = 0.06% and S rate X Time - LSD(0.05) = 0.14%.
Sulfur Concentration - N rate - LSD(0.05) = 0.01% and S rate X Time - LSD(0.05) = 0.02%.
N/S Ratio - S rate X Time - LSD(0.05) = 2.42.

First-1988-89: Nitrogen Concentration - N rate - LSD(0.05) = 0.06% and S rate X Time - LSD(0.05) = 0.13%.
Sulfur concentration - S rate X Time - LSD(0.05) = 0.01.
N/S Ratio - S rate X Time - LSD(0.05) = 1.07.

[$] Conv = Conventional tillage. Reduced = Reduced tillage.

[@] N/S = nitrogen to sulfur ratio.

1988. Percentage leaves was not affected by either the rate of sulfur or the rate of nitrogen ($P \leq 0.05$) during either year of the study. In 1988 leaf percentage average 38% at Brewton and 51% at Headland.

Forage Quality. Forage from selected treatments and cuttings were analyzed for several parameters that evaluate the quality of forage for feed (Table 17). During the first year of the study samples from the last harvest were analyzed since only one cutting was taken on the Benndale soil. Forage quality during the first year was not affected by the rate of sulfur ($P \leq 0.05$) added as phosphogypsum. Forage from the second cutting on the Dothan soil were analyzed during the second year of the study (1987-1988; Table 17). At the second cutting on the Dothan soil in 1987-1988 a yield response was obtained to added sulfur (Table 7). In addition crude and digestible protein were also increased ($P \leq 0.05$) by the rate of added sulfur. This shows that added fertilizer sulfur was producing a higher quality forage during a period when the demand for temporary forage would be the greatest. Analysis of forage from the Benndale soil for the third year are incomplete.

Soil Analyses

Chemical Properties. Soil samples were collected from selected treatments at three depth after the final wheat harvest during the first (Table 18 and 19) and second years (Tables 20 and 21) of the study. Phosphogypsum had no effect

Table 17. **Forage quality analysis of wheat forage samples collected from both experimental sites used to evaluate phosphogypsum as a source of fertilizer sulfur.**

Sulfur Rate	Crude Protein	Digestible Protein	NDF Fiber	Crude Fiber	Total Digestible Nutrients	Metab. Energy[!]	Ca	K	Mg	P
kg/ha	%					Mc/kg	%			
					Benndale, 1986 - 1987[@]					
0	13.4	8.99	47	23	68	2.57	0.37	1.0	0.15	0.24
22	11.6	7.27	48	22	68	2.56	0.37	0.9	0.13	0.21
45	10.1	5.91	48	23	67	2.54	0.32	1.0	0.12	0.21
90	15.5	6.32	48	23	68	2.56	0.31	1.2	0.11	0.22
LSD(0.05)	1.9	2.07	NS	NS	NS	NS	NS	NS	0.02	NS
					Benndale, 1987 - 1988[#]					
0	9.0	4.9	30	16	79	3.06	0.26	1.6	0.10	0.23
22	9.2	5.1	29	15	79	3.06	0.26	1.5	0.09	0.23
45	9.2	5.0	29	15	79	3.07	0.27	1.6	0.09	0.24
90	9.5	5.3	30	16	79	3.03	0.28	1.6	0.10	0.23
LSD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
					Dothan, 1986 - 1987[@]					
0	13.8	9.34	44	21	70	2.66	0.23	1.6	0.14	0.33
22	13.1	8.61	44	17	77	2.96	0.23	1.3	0.13	0.30
45	12.5	8.10	45	22	69	2.62	0.25	1.5	0.13	0.28
90	12.8	8.41	44	21	70	2.67	0.26	1.5	0.13	0.27
LSD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.05
					Dothan, 1987 - 1988[#]					
0	15.3	10.7	36	18	75	2.88	0.35	2.3	0.14	0.32
22	17.6	12.9	34	17	76	2.93	0.43	2.5	0.17	0.34
45	17.4	12.7	37	19	74	2.84	0.38	2.4	0.14	0.31
90	16.3	11.7	34	17	76	2.93	0.43	2.5	0.13	0.31
LSD(0.05)	1.5	1.3	2	1	1	0.05	0.04	NS	0.02	NS

@ Samples from the third cut.
# Samples from the second cut.
! Metabolizable energy.

Table 18. Effect of selected phosphogypsum and secondary treatments on soil chemical analysis data at three depths in the Benndale fine sandy loam.

Tillage	N Rate	Sulfur Rate	Time	pH	Ca	Mg	P	K	SO_4
	--- kg/ha ---				---- kg/ha -----				ppm
			0 to 15 cm						
Conv[@]	134	0	----	6.0	519	50	55	26	5.50
Conv	202	0	----	5.9	610	46	65	26	6.16
Conv	202	45	Fall	5.7	448	31	62	19	6.45
Conv	202	45	Spring	5.6	418	27	63	20	5.92
Reduced	134	0	----	6.4	661	60	67	22	4.20
Reduced	202	0	----	6.3	672	64	64	22	4.45
Reduced	202	45	Fall	6.5	902	54	67	19	4.75
Reduced	202	45	Spring	6.3	647	53	72	22	5.89
LSD(0.05) - Sulfur Rate				NS	128	8	NS	NS	NS
			15 to 30 cm						
Conv	134	0	----	5.8	367	49	28	43	4.71
Conv	202	0	----	5.8	362	53	36	37	3.04
Conv	202	45	Fall	5.8	426	50	34	35	3.89
Conv	202	45	Spring	5.9	409	48	32	28	4.73
Reduced	134	0	----	5.7	300	40	26	34	3.51
Reduced	202	0	----	5.7	414	53	50	38	5.85
Reduced	202	45	Fall	5.5	286	36	27	35	4.64
Reduced	202	45	Spring	5.4	295	44	35	36	9.05
LSD(0.05) - Sulfur Rate				NS	NS	NS	NS	NS	NS
			30 to 46 cm						
Conv	134	0	----	4.9	207	38	10	35	16.02
Conv	202	0	----	5.0	218	36	9	36	10.94
Conv	202	45	Fall	5.0	221	35	7	40	12.56
Conv	202	45	Spring	5.0	258	41	8	37	17.28
Reduced	134	0	----	5.2	269	39	10	40	10.38
Reduced	202	0	----	5.1	218	88	8	38	14.70
Reduced	202	45	Fall	5.0	278	58	18	46	13.26
Reduced	202	45	Spring	4.9	263	44	9	47	20.10
LSD(0.10) - Sulfur Rate				NS	NS	NS	NS	NS	2.79

[@] Conv refers to conventional tillage. Reduced refers to reduced tillage.

Table 19. Effect of selected phosphogypsum and secondary treatments on Soil chemical analysis data at three depths in the Dothan fine sandy loam.

Tillage	N Rate	Sulfur Rate	Time	pH	Ca	Mg	P	K	SO_4
	--- kg/ha ---				---- kg/ha ---				ppm
			0 to 15 cm						
Conv	134	0	----	6.4	750	100	81	62	3.30
Conv	202	0	----	6.1	720	76	83	43	1.49
Conv	202	45	Fall	6.0	681	60	67	31	2.76
Conv	202	45	Spring	6.0	687	67	69	39	5.88
Reduced	134	0	----	6.3	759	103	64	56	4.44
Reduced	202	0	----	6.2	769	94	60	55	4.73
Reduced	202	45	Fall	6.0	664	75	67	43	3.25
Reduced	202	45	Spring	6.2	728	83	60	45	4.23
LSD(0.05) - Sulfur Rate				NS	NS	NS	NS	8	--
LSD(0.05) - Nitrogen Rate				0.2	NS	12	NS	NS	NS
LSD(0.05) - Tillage X Sulfur				NS	NS	NS	NS	NS	1.81
			15 to 30 cm						
Conv	134	0	----	6.4	681	109	52	69	7.68
Conv	202	0	----	6.4	776	110	67	53	6.41
Conv	202	45	Fall	6.3	605	92	48	48	6.62
Conv	202	45	Spring	6.4	711	110	54	54	7.53
Reduced	134	0	----	6.0	515	81	41	54	5.68
Reduced	202	0	----	6.2	678	100	45	60	5.22
Reduced	202	45	Fall	5.9	485	74	49	52	6.04
Reduced	202	45	Spring	6.1	633	91	47	50	6.74
LSD(0.05) - Sulfur Rate				NS	64	NS	NS	NS	NS
			30 to 46 cm						
Conv	134	0	----	6.0	381	58	12	52	9.41
Conv	202	0	----	6.2	446	62	16	54	6.37
Conv	202	45	Fall	5.7	286	49	8	47	13.18
Conv	202	45	Spring	5.6	356	62	10	50	17.32
Reduced	134	0	----	5.8	345	45	8	53	9.62
Reduced	202	0	----	6.0	379	55	10	52	9.14
Reduced	202	45	Fall	5.6	319	53	10	50	11.01
Reduced	202	45	Spring	5.9	412	60	9	53	14.93
LSD(0.05) - Sulfur Rate				0.2	34	NS	NS	NS	2.65

@ Conv refers to conventional tillage. Reduced refers to reduced tillage.

Table 20. Effect of phosphogypsum (sulfur rate) on soil chemical properties in the spring of 1988 in a Benndale fine sandy loam.

Sulfur Rate	pH	Extractable Ca	Mg	P	K	SO_4
		----------kg/ha	--------			ppm
		0 to 15 cm				
0	5.6	420	32	77	39	6.2
45	5.9	528	30	79	35	7.2
LSD(0.05)	NS[@]	NS	NS	NS	NS	0.8
		15 to 30 cm				
0	5.7	366	50	43	45	6.9
45	5.8	394	36	37	44	9.0
LSD(0.05)	NS	NS	11	NS	NS	1.3
		30 to 45 cm				
0	5.2	195	37	6	39	14
45	5.2	240	52	4	41	19
LSD(0.05)	NS	NS	NS	NS	Ns	3

[@] NS = Nonsignificant.

Table 21. Effect of phosphogypsum (sulfur rate) on soil chemical properties in the spring of 1988 in a Dothan fine sandy loam.

Sulfur Rate	pH	Extractable Ca	Mg	P	K	SO_4
		-----------	kg/ha	---------		ppm
		0 to 15 cm				
0	5.8	535	52	73	45	8.4
45	5.9	572	48	63	38	8.0
LSD(0.05)	NS[@]	NS	NS	4	3	NS
		15 to 30 cm				
0	6.2	634	86	47	59	9.4
45	6.1	581	71	47	54	9.2
LSD(0.05)	NS	NS	10	NS	NS	NS
		30 to 45 cm				
0	6.2	348	78	8	61	11
45	6.0	318	63	8	62	16
LSD(0.05)	NS	NS	NS	NS	NS	3

[@] NS = Nonsignificant.

on most of the properties measured. A slight increase in extractable SO_4 was observed due to the rate of sulfur (phosphogypsum), particularly at the 30 to 46 cm depth. These soils contain low levels of clay (Table 1) and should not retain large amounts of extractable SO_4.

A more intensive soil sampling was conducted in the spring of 1989 at the end of the study (Tables 22 and 23). Extractable P, K and soil pH were not affected ($P \leq 0.05$) by the rate of sulfur added as phosphogypsum. Analysis of the data show that extractable calcium at 51 to 76 cm and 76 to 102 cm in the Benndale soil was increased by the higher rated of phosphogypsum. In the other soil layers, exchangeable calcium was not affected by the application of phosphogypsum. Exchangeable calcium in the Dothan soil (Table 23) was not affected by the application of phosphogypsum which suggests that the applied calcium was either taken up by the forage crops or leached out of the soil profile. The data also show that phosphogypsum had displaced some of the exchangeable magnesium in the surface 0 to 25 cm layer of soil (Tables 22 and 23). This displaced magnesium had not been leached out of the soil profile as shown by increases in exchangeable magnesium in both soils at the lower soil depths. Extractable SO_4 in the lower soil layers of both soils increased as the rate of sulfur increased. The greatest increase was observed

Table 22. Effect of phosphogypsum (sulfur rate) on soil Chemical properties in a Benndale fine sandy loam soil. Samples were collected at the termination of the field studies in 1989.

Sulfur Rate	pH	Extractable Ca	Mg	P	K	SO_4
		kg/ha				ppm
0 to 25 cm						
0	6.1	435	90	64	49	7.3
11	6.1	391	86	64	46	8.0
22	6.1	446	88	68	53	7.3
45	6.1	416	74	64	44	8.6
90	6.0	486	68	69	52	8.6
LSD(0.05)	NS[@]	NS	14	NS	NS	NS
25 to 51 cm						
0	5.1	174	44	4	43	16
11	5.1	172	48	4	43	18
22	5.3	217	53	3	48	17
45	5.0	194	47	6	46	19
90	5.0	203	53	4	46	26
LSD(0.05)	0.2	NS	NS	NS	NS	4
51 to 76 cm						
0	4.8	94	22	2	28	22
11	4.8	109	25	3	29	24
22	4.8	122	29	2	28	29
45	4.7	118	24	3	30	32
90	4.6	147	28	3	30	34
LSD(0.05)	0.1	18	NS	NS	NS	3
76 to 102 cm						
0	4.9	56	13	6	18	25
11	4.6	58	13	6	17	23
22	4.7	76	18	6	18	23
45	4.7	74	16	6	20	26
90	4.6	101	18	6	20	31
LSD(0.05)	NS	11	NS	NS	NS	3

[@] NS = Nonsignificant.

Table 23. Effect of phosphogypsum (sulfur rate) on soil chemical properties in a Dothan fine sandy loam soil. Samples were collected at the termination of the field studies in 1989.

Sulfur Rate	pH	Extractable Ca	Mg	P	K	SO_4
		-----------kg/ha	---------			ppm
0 to 25 cm						
0	5.8	559	53	54	49	14
11	5.8	512	44	55	41	11
22	5.8	539	41	58	43	9
45	5.7	520	32	63	40	11
90	5.7	563	31	65	44	14
LSD(0.05)	NS[@]	NS	8	NS	NS	NS
25 to 51 cm						
0	6.1	399	66	11	48	13
11	5.9	334	66	9	45	15
22	6.1	370	69	9	47	15
45	5.9	354	62	9	48	18
90	5.7	386	60	12	46	25
LSD(0.05)	0.2	NS	NS	NS	NS	4
51 to 76 cm						
0	5.4	306	44	1	38	30
11	5.3	324	57	1	40	36
22	5.4	289	58	1	43	34
45	5.2	301	56	1	39	43
90	5.2	284	58	2	39	51
LSD(0.05)	NS	NS	NS	NS	NS	9
76 to 102 cm						
0	5.2	867	58	0.7	38	79
11	5.1	654	71	0.7	44	92
22	5.9	678	76	0.4	44	94
45	5.2	694	75	0.4	45	100
90	5.1	628	85	0.6	44	108
LSD(0.05)	NS	NS	8	NS	NS	15

[@] NS = Nonsignificant.

Table 24. Effect of phosphogypsum (sulfur rate) and secondary treatments on wheat root density at maturity in 1987.

Tillage	Nitrogen Rate	Sulfur Rate	Time	Depth, cm 0 to 20	20 to 30
	----- kg/ha -----			-cm roots/cm^3 soil-	
Brewton					
Conv[@]	134	0	----	2.62	0.92
Conv	202	0	----	2.16	1.14
Conv	202	45	Fall	2.44	0.95
Conv	202	45	Spring	2.06	0.91
Reduced	134	0	----	2.41	0.43
Reduced	202	0	----	2.57	0.37
Reduced	202	45	Fall	2.25	0.24
Reduced	202	45	Spring	1.84	0.37
LSD(0.05) - Sulfur Rate				NS	NS
Headland					
Conv	134	0	----	3.89	1.11
Conv	202	0	----	4.04	0.96
Conv	202	40	Fall	4.70	1.90
Conv	202	40	Spring	4.46	1.95
Reduced	134	0	----	4.50	1.16
Reduced	202	0	----	4.27	0.33
Reduced	202	40	Fall	3.79	0.99
Reduced	202	40	Spring	3.10	1.30
LSD(0.05) - Sulfur Rate				NS	0.49

[@] Conv refers to conventional tillage -- turning with a moldboard plow and disking prior to planting. Reduced refers to reduced tillage -- disking the area prior to planting.

at the 76 to 102 cm depth in the Dothan soil. These data indicate that most of the applied sulfur may have leached out of the soil profile.

Root Growth. Wheat root density measurements for the upper 30 cm of soil in 1986-1987 are summarized in Table 24. The rate of sulfur did not influence wheat root density at either location. The reduced tillage system had the lowest root density in the 20 to 30 cm soil layer at both locations. This shows that in the reduced tillage system a larger proportion of the wheat roots are in the top 20 cm of soil. Root growth was evaluated indirectly in the spring of 1989 after the last wheat forage harvest by taking soil penetrometer measurements. Soil penetrometer readings were taken under both tillage systems from approximately every other plot (Fig. 1 and Fig. 2). Root growth is usually reduced if the cone reading is > 1.2 MPa. The data in Fig. 1 and Fig. 2 clearly show that more force is needed to penetrate soil in the reduced tillage system as compared to the conventional system. Since most of the reserve sulfur is in the subsoil (Tables 22 and 23) wheat roots in the reduced tillage system did not have full access to plant available sulfur. The reduced tillage system consistently gave lower wheat forage yields as compared to the conventional tillage system (Tables 3 - 9). Adding sulfur as phosphogypsum to the reduced tillage system increased wheat forage yields, but the yields were still lower as compared to the conventional tillage system. This suggests that yield reductions under the reduced tillage system were due to soil compaction (Fig. 1 and Fig. 2).

Radiological Analyses.

Radiological analyses were conducted on selected soil and forage samples from treatments receiving 0, 22 and 45 kg of sulfur per ha as phosphogypsum (Tables 25 - 27) during the first and third years of the study. The phosphogypsum used in this study contained 21 pCi Radium-226 per gram and 8.1 pCi Polonium-210 per kilogram. There was some concern about the fate of these isotopes in the soil-plant system receiving phosphogypsum. Analysis of this data suggests there is little or no effect of phosphogypsum on Radium-226 or Polonium-210 in harvested forage or in the treated soil.

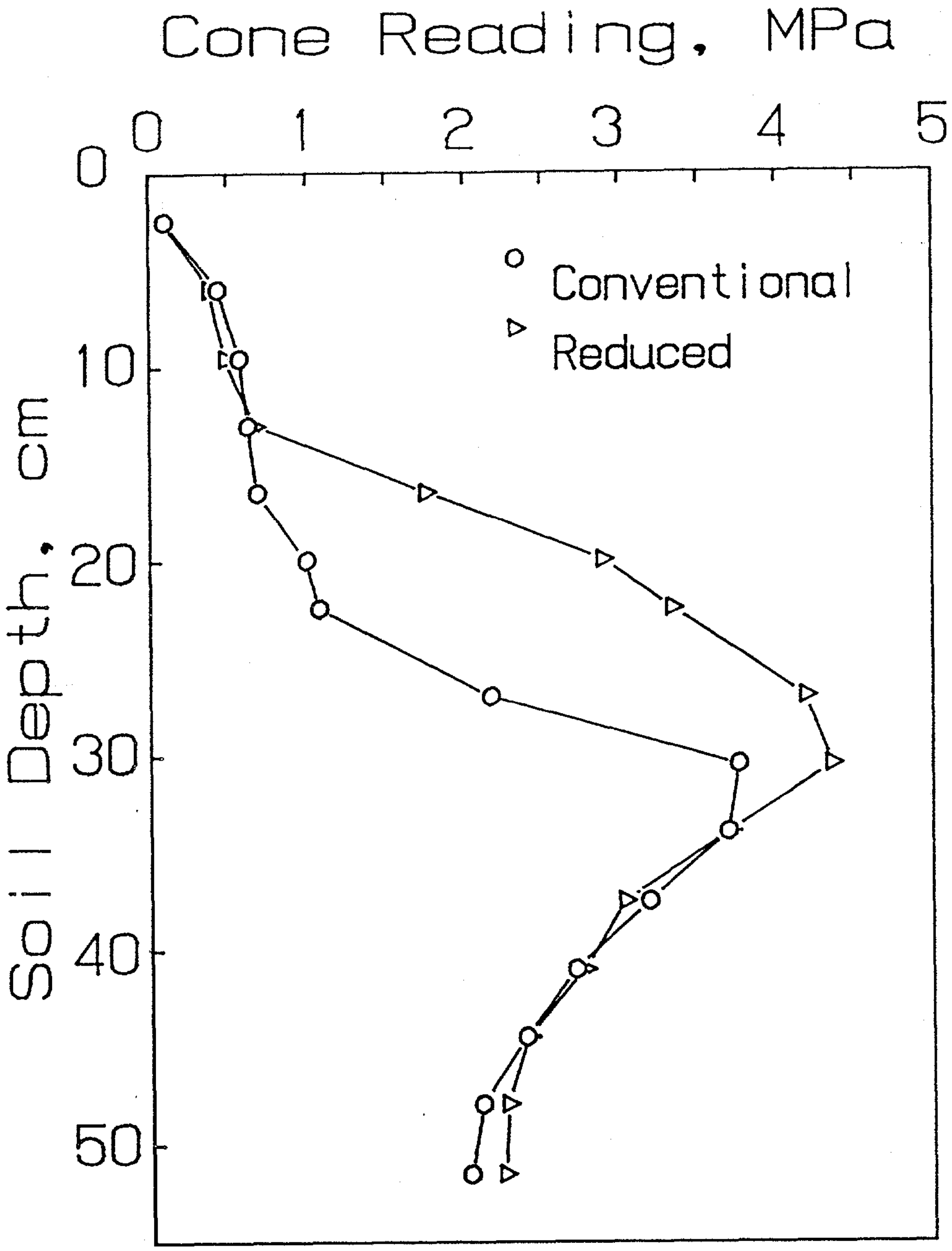

Figure 1. Soil penetrometer readings in the conventional and reduced tillage systems on the Benndale soil at the termination of the field studies in the spring of 1989.

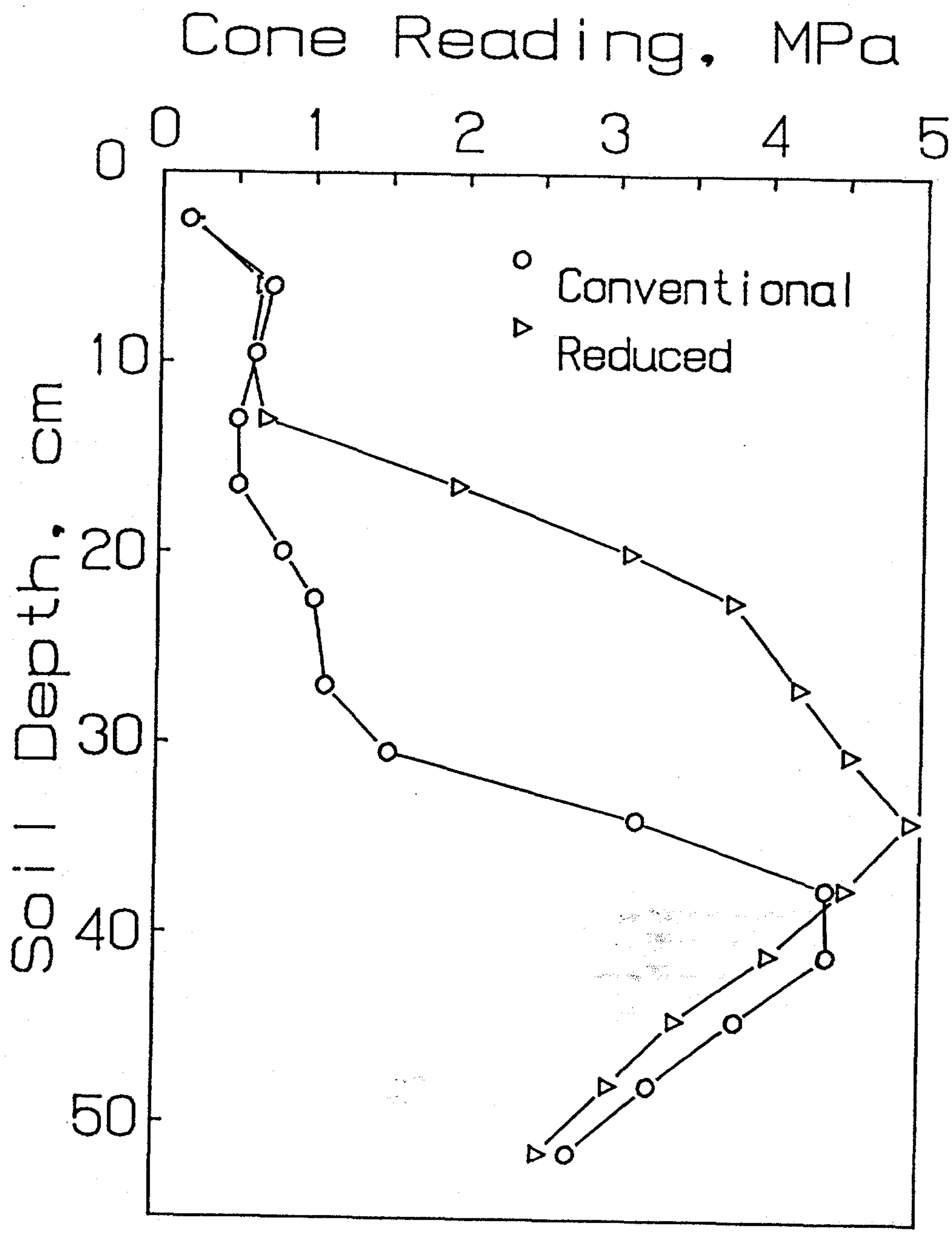

Figure 2. Soil penetrometer readings in the conventional and reduced tillage systems on the Dothan soil at the termination of the field studies in the spring of 1989.

Table 25. Effect of phosphogypsum (sulfur rate) on Radium-226 in harvested wheat forage on a Dothan and Benndale soil during 1986-1987.

Sulfur Rate	Dothan First Cut Ra-226	Dothan First Cut Po	Dothan Third Cut Ra-226	Benndale Ra-226	Benndale Po
- kg/ha -	pCi/gram				
0	0.08	0.44	0.07	0.04	0.08
22	0.09	0.44	0.07	0.06	0.08
45	0.09	0.36	0.06	0.04	0.07

The phosphogypsum contained 21 pCi Ra-226/gram and the agricultural gypsum contained 0.18 pCi Ra-226/gram

Table 26. Effect of phosphogypsum (sulfur rate) on Radium-226 in selected soil samples at the Dothan and Benndale soil during 1986-1987.

Sulfur Rate	Soil Depth	Dothan fsl	Benndale fsl
kg/ha	cm	pCi Ra-226/g	
0	0 to 15	0.22	0.33*
45	0 to 15	0.24	0.21@
0	15 to 30	0.31	0.35
45	15 to 30	0.32	0.17
0	30 to 46	0.29	0.20
45	30 to 46	0.19	0.27

* This soil layer also contained 0.48 pCi Polonium-210/g.
@ This soil layer also contained 0.36 pCi Polonium-210/g.

Table 27. Radiological analysis of selected soil and wheat forage samples as affected by the rate of sulfur added as phosphogypsum. Forage samples are for the first harvest during the 1988-1989 season and soil samples were collected at the end of the field studies in 1989.

Sulfur Rate	Soil Depth, cm 0 to 25	25 to 51	51 to 73	76 to 102	Wheat forage Ra-226	Po-210[#]
kg/ha	pCi Ra-226/g				pCi/g	pCi/kg
			Brewton			
0	0.15	0.10	0.10	0.23	0.13	0.25
22	0.15	0.18	0.18	0.10	0.10	0.17
45	0.10	0.15	0.10	0.08	0.10	0.20
LSD(0.10)	NS	0.05	0.04	0.08	NS	--
			Headland			
0	0.25	0.25	0.23	0.35	0.10	--[@]
22	0.30	0.23	0.23	0.33	0.15	0.10
45	0.25	0.18	0.20	0.28	0.18	0.17
LSD(0.10)	NS	NS	NS	NS	NS	--

[#] The laboratory was not able to detect Po-210 in several samples, and thus statistical analysis of the data was not conducted.

[@] Unable to detect.

CONCLUSIONS AND RECOMMENDATIONS

Wheat forage yields were affected by tillage during the third year of the study on the Benndale soil and during all three years of the study on the Dothan soil. During the third year of the study on the Benndale soil average yields were 38% higher under conventional tillage as compared to the reduced tillage system. On the Dothan soil the conventional tillage system produced an average of 33.6% more forage as compared to the reduced tillage system. Root density and soil penetrometer measurements showed that lower yields under reduced tillage resulted from soil compaction

As expected, forage yields were increased with increasing rates of nitrogen. On the Benndale soil average forage yields were increased by an average of 13.3% by increasing the nitrogen rate from 134 to 202 kg per ha. When averaged over the three years, the 202 kg nitrogen per ha rate increased forage yields 18.6% as compared to the 134 kg nitrogen rate on the Dothan soil.

Wheat responded to the application of sulfur (phosphogypsum) at both locations, but the greatest response was obtained on the Dothan soil. On the Benndale soil, three-year average yields were increased by 5.4% by the application of sulfur. Wheat forage yields on the Dothan soil were increased by an average of 9.3% by the application of sulfur. The greatest yield response was obtained at the second cutting during the second year of the study on the

Dothan soil. Yields at this harvest were increased 34% by the applied sulfur. Response to the time of sulfur application was inconsistent and varied among sites. During the first two years of the study an average of 6% higher yields were obtained by applying sulfur in the spring to the Benndale soil. In contrast, an average of 8% higher yields were obtained during the second and third years of the study by applying sulfur in the fall. Results from both locations show that maximum forage yields were obtained when 22 to 45 kg of sulfur were applied per ha as phosphogypsum. Statistical analysis showed that there were no differences in forage yields between phosphogypsum and agricultural grade gypsum when applied at a rate of 45 kg of sulfur per ha. Yield responses to added sulfur were generally greater under reduced tillage as compared to the conventional tillage system, however, tillage effects were not completely eliminated by applying higher rates of sulfur as phosphogypsum.

Nitrogen concentration in harvested wheat was increased by the rate of nitrogen and the concentration of sulfur was increased by added sulfur. Nitrogen:sulfur ratios tended to decrease with increasing rates of phosphogypsum indicating that a higher quality forage was being produced. Based on nitrogen:sulfur ratios, in some instances a higher quality forage was being produced at the 45 and 90 kg per ha sulfur rates although wheat yields leveled off at 22 to 45 kg of sulfur per ha. During the second year of the study, crude and digestible protein were increased in forage from the second cutting on the Dothan soil by the application of sulfur. Percentage of leaves and stems in harvested wheat were not affected by any fertility treatments.

The phosphogypsum contained 21 pCi Radium-226 per gram and 8.1 pCi Polonium-210 per kilogram. Analysis of selected soil and forage samples showed that there were little if any effects of phosphogypsum on the levels of these isotopes in either the soil or harvested forage.

The application of phosphogypsum increased the level of extractable SO_4 in the subsoil at each location. Relative increases in extractable subsoil SO_4 suggest that most of the applied sulfur may have leached out of the rooting zone. The application of phosphogypsum resulted in a displacement of exchangeable magnesium in the surface 0 to 25 cm of soil.

Results of this three year field study show that yield increases in wheat forage can be expected by applying sulfur as phosphogypsum to deep, sandy soils located in the coastal plain region of Alabama. Phosphogypsum was shown to be an acceptable source of fertilizer sulfur for annual forage production. Maximum yields were obtained at approximately 22 kg of sulfur per ha. Performance of grazing livestock would be expected to increase due to the increase in forage yield and a reduction in the N/S ratio in the forage. Actual increases in livestock performance cannot be estimated since this type of grazing study has not been conducted in the

Southeastern U.S. In Alabama there are approximately 429,000 acres of winter annuals grown for forage on prepared land. There are also approximately 86,000 acres of wheat that are grazed early and allowed to produce grain. A total of 30,560 Mg (33,660 tons) of phosphogypsum would be used annually if 22 kg of sulfur were applied per ha (20 pounds per acre). This does not include the permanent and improved pasture land located in Alabama (4.34 million acres) and Florida (13 million acres) which represents a potential annual use of 1.0 million Mg (1.13 million tons). This potential use of phosphogypsum would not only increase forage yields and possibly livestock performance in this area, but it would also help decrease the stockpiles of gypsum produced by the phosphate fertilizer industry. Currently, the approximate price for agricultural gypsum (bulk, F.O.B.) in South Alabama is $64 per ton. Spreading costs would add an additional $4.50 to $8 per ton. Obviously the cost of phosphogypsum would have to be competitive with the available agricultural gypsum used in this area.

Results from this study suggest that grazing studies should be conducted as a follow up. These studies should seek to determine if the increases in forage yields and forage quality due to added sulfur are translated into increased livestock performance. Some additional studies could be conducted with different sources of calcium and sulfur to ensure that the response obtained was due to added sulfur and not to added calcium.

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APPENDIX

A. Profile description of the Benndale soil. Information was taken directly from the Soil Survey of Escambia County, Alabama.

<u>Benndale series</u>

The series consists of well-drained soils on uplands. The soils formed in unconsolidated beds of sandy loams and sandy clay loams. Slopes are 0 to 8 percent.

Al-O to 6 inches, very dark grayish-brown (10YR 3/2) fine sandy loam; weak, fine, granular structure; very friable; strongly acid; clear wavy boundary.

A2-6 to 12 inches, brown (10YR 4/3) sandy loam: weak, fine, granular structure; very friable; strongly acid; gradual, wavy boundary.

Bl-12 to 19 inches, dark yellowish-brown (10YR 4/4) sandy loam; weak, medium, subangular blocky structure; friable; sand grains are coated and bridged; very strongly acid: gradual, wavy boundary.

B21t-19 to 40 inches, yellowish-brown (10YR 5/8) sandy loam; weak, medium, subangular blocky structure; friable: few, very thin, patchy clay films; very strongly acid; clear, wavy boundary.

B22t-40 to 59 inches, yellowish-brown (10YR 5/8) sandy clay loam; few, fine, distinct, strong-brown and yellowish-red mottles; weak, medium, subangular blocky structure; friable; few clean sand grains; few, thin, patchy clay films; very strongly acid; gradual, wavy boundary.

B23t-59 to 88 inches, yellowish-brown (10YR 5/8) sandy clay loam: common, fine and medium, strong-brown mottles, few, fine and medium, pale-yellow mottles, and few, fine, prominent, red mottles; weak, medium and coarse, subangular blocky structure; friable; few thin clay films; less than 5 percent plinthite; very strongly acid.

B. Profile description of the Dothan soil. Information was taken directly from the Soil Survey of Houston County, Alabama.

Dothan series

The series consists of deep, well drained soils developed in thick beds of medium-textured marine deposits. The slope range is 0 to 8 percent.

Ap-0 to 6 inches, dark grayish-brown (10YR 4/2) loamy sand; weak, fine, granular structure; very friable; strongly acid; abrupt, smooth boundary.

B1-6 to 13 inches, yellowish-brown (10YR 6/6) sandy loam; very weak, medium, subangular blocky structure; very friable when moist; uppermost 2 inches of this horizon is a massive brittle plowpan; strongly acid; gradual, smooth boundary.

B21t-13 to 28 inches, yellowish-brown (10YR 5/8) sandy clay loam; weak, medium, subangular blocky structure; firm when moist, slightly plastic when wet, hard when dry; thin, discontinuous clay films on surfaces of peds; strongly acid; diffuse, smooth boundary.

B22t-28 to 33 inches, yellowish-brown (10YR 5/8) sandy clay loam with common, medium distinct mottles of strong brown (7.5YR 5/8) and yellowish red (5YR 4/8); weak, medium, subangular blocky structure; friable when moist, slightly sticky when wet, hard when dry; thin discontinuous clay films on surfaces of peds; strongly acid; clear, wavy boundary.

Bx-33 to 60 inches +, mottled yellowish-brown (10YR 5/8), strong-brown (7.5YR 5/8), red (2.5YR 4/8), yellow (10YR 7/8), and white (10YR 8/2) sandy clay loam [the grayer parts are sandy clay, and the redder parts are strongly acid, cemented sandy loam (soft plinthite)]; massive; very firm and compact when moist, very hard when dry, gray and yellow mottled parts are plastic when wet; strongly acid.