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Effects of Magnesium and Sulphur On Growth and Chemical Composition of Clover on Fourteen Coastal Plain Soils in Louisiana

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Magnesium is a constituent of chlorophyll, which imparts green color to plants and is required in photosynthesis. Consequently, an adequate supply of this essential plant nutrient is necessary for optimum growth and reproduction. The formation of oil in seeds as well as the synthesis of nucleo-protein appears to be associated with the absorption and utilization of magnesium. It has been found by some scientists that the role of magnesium in these processes is also closely related to phosphates (*26*)[2].

Sulphur is also apparently essential for the formation of chlorophyll since the development of green pigment is often retarded in sulphur deficient plants (*20*). However, sulphur is not a constituent of chlorophyll.

Nutritional problems involving magnesium and sulphur, and possibly some micronutrients, develop with the use of higher-analysis fertilizers, which are generally free of the impurities ordinarily contained in lower analysis materials (*28*).

Frequently on the upland soils of Louisiana, low levels of magnesium are associated with low levels of calcium. Soil test summary data (*19*) indicate that the Coastal Plain Soils of Louisiana often contain low amounts of available magnesium. Vernon, Winn, and Union parishes and the hill sections of Caddo and Bossier parishes are the areas where this element is the lowest. Seventy-five per cent of the samples tested low in these areas. A deficiency of calcium and magnesium usually results in a low degree of base saturation and the development of a high degree of acidity (*22*). For this reason, consideration should be given to the pH, the degree of base saturation, and the contents of available magnesium and calcium in order to determine the need of a soil for lime.

Greenhouse studies were conducted on 14 soils of the Coastal Plain areas of Louisiana. The objectives were: (a) to determine the level of available soil magnesium at which response to added magnesium could be expected, and (b) to investigate the influence that fertilizers containing sulphur might have on the response to added magnesium.

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[2]Figures in parentheses refer to literature cited on pages 18 and 19.

Review of Literature

In a review of literature of magnesium research, Brown (*4*) pointed out that the majority of the magnesium research work has been in the field of horticultural crops. Potatoes, beans, tomatoes, and citrus have been investigated most frequently. In the field of forage and grain crops, soybeans, alfalfa, wheat and corn have been tested more frequently with only occasional data reported for grasses. Applications of magnesium seldom result in marked increases in yield of forage crops and much of the study of magnesium has dealt with factors other than yield response.

Both plant and soil analysis have been used to evaluate the availability of soil magnesium. Magnesium contents of leaves have been used to determine the availability of soil magnesium (*10, 12, 15, 18*). Bear and Prince (*3*) concluded that Coastal Plain soils are most likely to be deficient in magnesium. This is because of the low amount of magnesium originally present in the soil and the depressive effect that potassium has on magnesium. Results of work in Alabama showed that some coarse-textured Coastal Plain soils became magnesium deficient following intensive cropping in the greenhouse (*23*). Crotolaria and peanuts responded most while corn responded least to magnesium fertilization. Cotton and crimson clover gave considerable response and turnips, relatively little. Although crop yield data showed a response of certain crops to magnesium on some soils, a correlation between crop response and magnesium content of the soil indicated that crop response could not be predicted from the magnesium content of the soil. Magnesium deficiencies in the Southeast have also been observed on highly fertilized soils with vegetables, tobacco, and citrus (*6, 7, 16*). Prince, Zimmerman, and Bear (*21*) concluded that if magnesium constitutes less than 6 per cent of the exchange cations in the soil, crops growing on that soil are likely to respond markedly to application of soluble magnesium. The ideal amount of magnesium is believed to be approximately 10 per cent of the total exchange capacity of the soil. Response to magnesium additions is governed in part by the ratio of magnesium to the other cations on the exchange complex. The ideal ratios are 65 per cent calcium, 10 per cent magnesium, 5 per cent potassium and 20 per cent allotted to hydrogen.

Lancaster (*15*) studied the magnesium status of blackland soils of Mississippi. He found that an excellent relationship existed between percentage saturation of the soil exchange complex with magnesium and the magnesium content of leaves of cotton grown on these soils. Therefore, either chemical analysis of selective leaf samples or the soil may be employed to predict the need of magnesium for profitable cotton production. He predicted that response to magnesium would not be expected if magnesium constituted more than 6.4 per cent of the cation exchange complex of the soil and if the magnesium content of the cotton leaves was more than 25 me. per 100 grams.

Graham, Powell, and Carter (*11*) studied the response of soybeans grown on 15 Missouri soils under intensive greenhouse cropping conditions. The highest correlation between the amount of magnesium shown by soil test and per cent increases in yield was obtained when the soil was extracted with 0.05N HCl. The amount of magnesium extracted was more highly correlated with the percentage of increase in yield from added magnesium than were the calcium-magnesium ratios or the percentage of magnesium saturation. The authors concluded, however, that soils in which magnesium represented less than 10 per cent of total cation exchange capacity showed yield response to added magnesium.

Adams and Henderson (*1*) studied the availability of soil magnesium on seven major soil types of Alabama by growing Sudan grass and Ladino clover in the greenhouse. They showed that a yield response to magnesium was obtained on soils that had less than 4 per cent of the cation exchange capacity represented by magnesium. Per cent magnesium saturation proved to be a better indicator of available magnesium than did exchangeable magnesium or the ratio of exchangeable magnesium to potassium.

It appears to be established that magnesium in plant nutrition acts as a carrier of phosphorus. The literature dealing with magnesium-phosphorus relationships in plant nutrition has been reviewed by Truog, Goates, Gerloff, and Berger (*26*). The results of most of the past experiments reveal a positive correlation between magnesium and phosphorus. Truog and his associates studied the relationship of the supply of magnesium to phosphorus content of pea seeds by field and culture test in which the supplies of available magnesium and phosphorus were varied. Increases in phosphorus content occurred with increasing amounts of available magnesium. Increasing supplies of available magnesium increased the phosphorus content of the peas much more than did increasing supplies of available phosphorus. It was concluded that attention should be given to supplies of available magnesium in soils in order that the phosphorus present in the soil might be used more efficiently. Tucker and Smith (*27*) found a definite positive correlation between phosphorus and magnesium in red clover plant material. Correlation was high on soils which were relatively low in degree of magnesium saturation. Bartholomew (*2*) studied the availability of phosphate fertilizers and noted that plants took up increased amounts of phosphorus when magnesium sulphate was added.

Jacob (*12*) recently reviewed research on fertilizer experiments with magnesium. He reported on pot experiments with oats in which the effect of the magnesium ion and the sulphate ion was studied. It was reported that the effect of the magnesium ion was especially favorable if it was applied in combination with the sulphate ion.

Jeane (*13*) studied the relationships of sulphur, magnesium and phosphorus in the nutrition of white clover. He found that treatments of dolomitic lime and sulphur gave significantly higher yields of clover than those obtained from dolomitic limestone without sulphur when superphosphate and treble superphosphate were used. The relationships between the absorption of sulphur, phosphorus, and magnesium as shown by the correlation coefficients indicate that added sulphur enhances the absorption of native magnesium in the soil and that magnesium enhances the absorption of phosphorus.

Conrad, Hall, and Chaugule (*8*) conducted experiments in which they applied 100 pounds per acre of elemental sulphur, 250 pounds per acre of treble superphosphate, and sulphur plus phosphate at the same rate as singly. Though some increases were noted from the treble superphosphate alone, they were small in comparison with the sulphur responses. They may have resulted in part from the small quantities of sulphur present in the phosphate fertilizer. Applications of sulphur resulted the first year in a three- to four-fold increase in yield of dry matter obtained for legumes, principally for clover. In the years following, yields of nonlegumes following the sulphured legumes were increased up to double the yields of the unfertilized plots.

Recent experimental evidence indicates that the presence of the sulphate ion may have a significant effect on phosphorus uptake by plants (*24*). It was found that when ammonium sulphate is mixed with a water soluble phosphatic fertilizer and applied in a band, there is a great proliferation of roots in the band and a greatly increased uptake of phosphorus by the plant. The effect does not occur when the nitrogen is in the nitrate form, nor does it occur if the sulphate ion is not present.

In field experiments conducted in the South, sulphur-free fertilizers applied alone and with supplements of sulphur as gypsum were compared. Supplementary sulphur increased yields in 15 of 22 experiments with cotton, forage crops, and tobacco (*14*). A positive phosphorus and sulphur interaction was indicated. Sulphur had no effect on yield of clover at the minimum phosphorus level. At adequate phosphorus levels and higher levels of sulphur, yields of dry matter were about five times the production of clover in the absence of sulphur.

Experimental

Acidic soils considered to be relatively low in dilute acid extractable or exchangeable magnesium were selected for greenhouse studies. Soils from the Coastal Plain areas of Louisiana used in this investigation included the following series: Bowie, Ruston, Shubuta, Lakeland, Eustis, Luverne, Orangeburg, and Kirvin. Cation exchange capacity varied from 2.7 to 6.4 me. per 100 gms. of soil. Initially the reaction of the soils included a pH range from 5.2 to 6.0. For the purpose of identification and convenience in reporting, each soil is assigned a number from 1 through 14. Soil identification and specific chemical properties are listed in Table 1. Bulk samples of surface soil were collected. The soil material was screened and 16 pounds of dry soil was placed in two-gallon pots.

TABLE 1.—Chemical properties of selected Coastal Plain soils

Soil No.	Soil Type	Location (Parish)	Extractable P	Extractable Mg	Extractable Ca	Extractable K	pH	Cation Exch. Cap.	Exch. Mg
			– – Parts per million – –					me./100gm.	%
1	Bowie fsl*	Vernon	9	25	216	39	5.2	4.40	4.7
2	Ruston sl	Washington	5	21	108	26	5.3	2.93	5.9
3	Ruston lfs	Claiborne	9	23	194	39	5.8	2.72	6.9
4	Shubuta fsl	Claiborne	9	25	130	39	5.5	3.20	6.4
5	Lakeland ls	Claiborne	43	30	216	30	5.9	3.39	7.2
6	Ruston sl	Ouachita	9	52	475	48	6.0	6.37	6.7
7	Eustis lfs	Bienville	53	27	216	39	5.8	2.96	7.5
8	Ruston sl	Vernon	109	33	432	30	5.7	4.00	6.7
9	Luverne fsl	St. Helena	20	43	259	48	5.9	4.53	7.8
10	Ruston fsl	Red River	36	28	136	36	5.5	2.76	8.3
11	Lakeland fs	Bienville	56	21	181	14	5.6	2.93	5.9
12	Ruston sl	Winn	20	25	227	27	5.7	4.04	5.1
13	Orangeburg sl	Ouachita	80	60	346	86	6.0	4.65	10.6
14	Kirvin fsl	Bienville	31	55	272	82	5.3	4.73	9.9

*fsl, fine sandy loam; sl, sandy loam; lfs, loamy fine sand; ls, loamy sand; fs fine sand.

Studies were conducted to determine the effects of different sources of phosphorus, magnesium, and liming materials on the growth of Ladino clover. Ground oyster shells and dolomitic limestone were used with two sources of phosphorus with and without the application of soluble magnesium. Soluble magnesium at the rate of 32 pounds of MgO per acre was applied as sulphate of potash-magnesia (Sul-Po-Mag) containing 18.5 per cent MgO and 21.5 per cent K_2O. Liming materials were applied in an amount sufficient to raise the pH of the soil to approximately 6.5. All soils received the equivalent of 24 pounds of nitrogen as amonium nitrate, 96 pounds of P_2O_5 (42 pounds of P) and 96 pounds of K_2O (80 pounds of K) per acre. The sources of phosphorus were ordinary superphosphate, 20 per cent P_2O_5, and concentrated superphosphate, 48 per cent P_2O_5. Potassium chloride, 60 per cent K_2O, and sulphate of potash-magnesia were used as the sources of potassium.

Studies were also conducted to determine the effects of sources of liming materials, magnesium and sulphur on the growth of Ladino clover and Tensas red clover. Magnesium nitrate, calcium sulphate, and sulphate of potash-magnesia (Sul-Po-Mag) were applied with ground oyster shells. A treatment was also included which did not contain magnesium or sulphur, and this served as the control. Dolomitic limestone was used with and without calcium sulphate. Ground oyster shells and dolomitic limestone were applied in an amount sufficient to raise the pH of the soil to approximately 6.8. All soils received the equivalent of 36 pounds of nitrogen, 144 pounds of P_2O_5, (63 pounds of P) and 144 pounds of K_2O (120 pounds of K) per acre. Concentrated superphosphate containing 48 per cent P_2O_5 was the source of phosphorus. Soluble magnesium, at the rate of 48 pounds of MgO per acre, was applied as sulphate of potash-magnesia and magnesium nitrate. Sulphur was applied at a rate of 60 pounds per acre as calcium sulphate and sulphate of potash-magnesia. The sources of nitrogen were ammonium nitrate and magnesium nitrate. Potassium chloride and sulphate of potash-magnesia served as sources of potassium.

The soils under the different treatments were planted to clover. The clover was clipped three or four times, depending upon its growth. The plant material was dried at 70° C. and weighed. Total weights in grams per pot are presented in Tables 2 and 5. Dry plant material was analyzed for magnesium, phosphorus, and sulphur by the methods described by Toth, Prince, Wallace, and Mikkelsen (*25*). Soil magnesium, calcium, and potassium were extracted with 0.1N hydrochloric acid. The soil-solution ratio was 1:20 and extracting time was 15 minutes. The concentration of calcium and potassium were determined with a Perkin-Elmer flame photometer, using lithium as an internal standard. Magnesium was determined by the Clayton yellow colorimetric method (*17*). Phosphorus was extracted with 0.1N hydrochloric acid solution containing 0.03N ammonium fluoride solution at a 1:20 soil to solution ratio as described by Byrnside and Sturgis (*5*). Color intensity was measured with a Bausch and Lomb spectrophotometer. Soil reaction was determined with a Leeds and Northrup glass electrode pH meter using a 1:1 soil-water suspension that had been allowed to stand 12 hours. Total exchange capacity, reported in milliequivalents per 100 grams of dry soil, was determined by agitating and leaching the soil with 0.5N barium acetate adjusted to pH 7.5 as recorded by Driskell (*9*).

Discussion of Results

Effects of Nutrient Sources on Yield and Nutrient Uptake

The results of greenhouse experiments on effects of different sources of phosphorus and magnesium on the yield of Ladino clover grown on five Coastal Plain soils in Louisiana are reported in Table 2. Soils included in this investigation are Bowie fine sandy loam, Ruston sandy loam, Ruston loamy fine sand, Shubuta fine sandy loam, and Lakeland loamy sand. In general, the data indicate that higher clover yields were obtained from the addition of superphosphate than from concentrated superphosphate when soluble magnesium was not included in the treatment. Significant increases in yield of clover were obtained when soluble magnesium was used with concentrated superphosphate. However, soluble magnesium did not always increase the yield of clover when superphosphate was the source of phosphorus. When ground oyster shells were used and superphosphate served as the source of phosphorus, soluble magnesium failed to increase the yield of clover grown on Ruston sandy loam and Ruston loamy fine sand. On these two soils, the sulphate as calcium sulphate in the ordinary superphosphate increased yield

TABLE 2.—Effects of liming materials, sources of phosphorus, and magnesium on yield of Ladino clover grown on five Coastal Plain soils

Treatments*	Bowie fsl (1)	Ruston sl (2)	Ruston lfs (3)	Shubuta fsl (4)	Lakeland ls (5)	Average five soils
	– – – – – – – – Yield, grams per pot – – – – – –					
Oyster shells						
Superphosphate	23.4	19.5	19.5	31.8	25.5	23.9
Superphosphate + Mg**	26.8	17.2	19.4	32.3	29.4	25.0
Conc. Superphosphate	20.8	14.0	13.8	29.7	18.4	19.3
Conc. Superphosphate + Mg	28.8	16.8	16.8	32.6	28.2	24.6
Dolomitic Limestone						
Superphosphate	20.9	16.7	14.2	33.1	26.0	22.2
Superphosphate + Mg	22.0	14.2	19.0	30.1	27.3	22.5
Conc. Superphosphate	19.7	15.3	16.8	22.0	19.5	18.7
Conc. Superphosphate + Mg	23.9	17.3	21.5	28.8	26.2	23.5
L.S.D. @ 5%	1.1	1.0	1.5	1.1	1.2	
L.S.D. @ 1%	1.5	1.3	2.0	1.4	1.6	

*All treatments received the equivalent of 24 pounds of nitrogen, 96 pounds of P_2O_5, and 96 pounds of K_2O per acre.

**Soluble magnesium applied as sulphate of potash-magnesia (Sul-Po-Mag) containing 18.5 per cent MgO and 21.5 per cent K_2O.

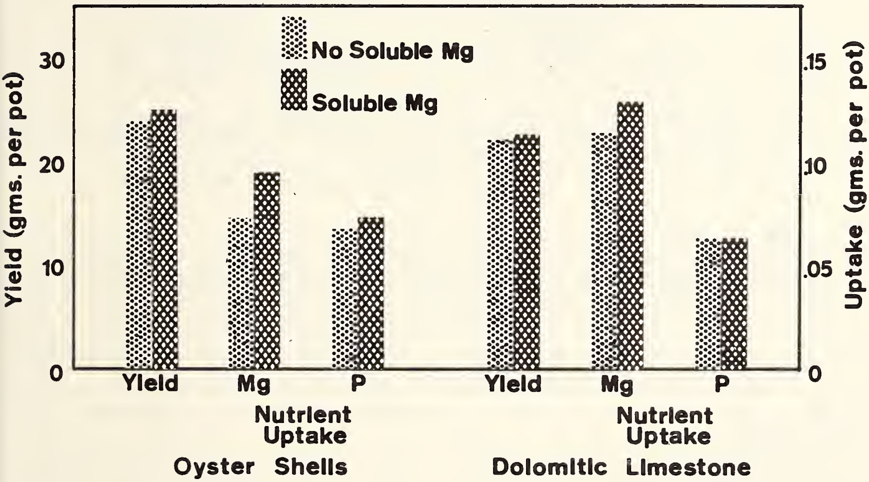

FIGURE 1.—Effect of soluble magnesium as sulphate of potash-magnesia on yield of clover and plant nutrient uptake when ordinary superphosphate served as the source of phosphorus (Five soils listed in Table 2).

of clover more than added magnesium and sulphate supplied by sulphate of potash magnesia.

Total magnesium and phosphorus uptake by clover are presented in Tables 3 and 4 and Figures 1 and 2. In this discussion, plant nutrient uptake data is used as a measure of magnesium and phosphorus availability. The effect of ordinary superphosphate with soluble magnesium on yield of clover and uptake of magnesium and phosphorus, as an average of five Coastal Plain soils, is presented in Figure 1. Yield of clover was increased slightly by the addition of a soluble source of magnesium when ground oyster shells were used as the liming material. This increase amounted to 4.9 per cent. A corresponding increase in the uptake of phosphorus was observed. When dolomitic limestone was used as the liming material, the addition of a soluble source of

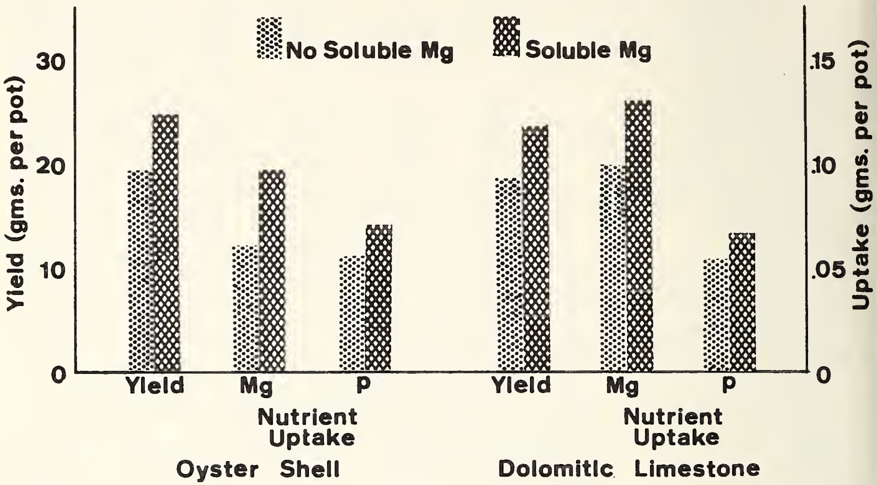

FIGURE 2.—Effect of soluble magnesium as sulphate of potash-magnesia on yield of clover and plant nutrient uptake when concentrated superphosphate served as the source of phosphorus (Five soils listed in Table 2).

TABLE 3.—Effects of liming materials, sources of phosphorus, and magnesium on magnesium uptake by Ladino clover grown on five Coastal Plain soils

Treatments*	Bowie fsl (1)	Ruston sl (2)	Ruston lfs (3)	Shubuta fsl (4)	Lakeland ls (5)	Average five soils
	– – – Magnesium uptake, mg. per pot – – –					
Oyster shells						
Superphosphate	96	44	65	89	73	73
Superphosphate + Mg**	128	51	78	117	95	94
Conc. Superphosphate	74	34	50	86	57	60
Conc. Superphosphate + Mg	125	51	74	117	95	92
Dolomitic Limestone						
Superphosphate	129	70	93	154	125	114
Superphosphate + Mg	144	64	132	160	139	128
Conc. Superphosphate	107	77	119	99	87	98
Conc. Superphosphate + Mg	143	82	126	157	144	130

*All treatments received the equivalent of 24 pounds of nitrogen, 96 pounds of P_2O_5, and 96 pounds of K_2O per acre.

**Soluble magnesium applied as sulphate of potash-magnesia (Sul-Po-Mag) containing 18.5 per cent MgO and 21.5 per cent K_2O.

magnesium had no significant effect on yield. Likewise, the uptake of phosphorus was not influenced by the inclusion of soluble magnesium in the fertilizer treatment.

Yield and nutrient uptake of clover grown on five Coastal Plain soils that received concentrated superphosphate are summarized in Figure 2. When a soluble source of magnesium was applied, a yield increase of 26.8 per cent was recorded when both oyster shells and dolomitic limestone were used. A corresponding increase of 24.8 per cent in the uptake of phosphorus was obtained. Since the source of soluble magnesium employed in this investigation was sulphate of potash-magnesia, response to additions of this material was thought to be due to magnesium or sulphur or the combined effect of both magnesium and sulphur on growth and chemical composition of clover.

By comparing data included in both Figures 1 and 2, it can be seen that 21.4 per cent higher clover yields were obtained when ordinary superphosphate served as the source of phosphorus and soluble magnesium was not used. Correspondingly higher magnesium and phosphorus uptakes were also obtained. This indicates that sulphates in ordinary superphosphate increased the availability of native soil magnesium and increased the uptake of phosphorus. Ordinary superphosphate, when used with dolomitic limestone, increased the availability of magnesium. Recent experimental evidence indicates that the presence of the sulphate ion may have a significant effect on phosphorus uptake by plants (*24*). Jeane (*13*) reported that the application of sulphur increases the availability of native soil magnesium.

TABLE 4.—Effects of liming materials, sources of phosphorus, and magnesium on phosphorus uptake by Ladino clover grown on five Coastal Plain soils

Treatments*	Bowie fsl (1)	Ruston sl (2)	Ruston lfs (3)	Shubuta fsl (4)	Lakeland ls (5)	Average five soils
	---- Phosphorous uptake, mg. per pot ----					
Oyster shells						
Superphosphate	62	57	48	87	87	68
Superphosphate + Mg**	69	50	51	96	100	73
Conc. Superphosphate	46	40	40	83	68	55
Conc. Superphosphate + Mg	66	48	45	89	102	70
Dolomitic Limestone						
Superphosphate	54	48	39	90	86	63
Superphosphate + Mg	58	42	47	71	95	63
Conc. Superphosphate	49	47	46	53	74	54
Conc. Superphosphate + Mg	60	51	54	72	94	66

*All treatments received the equivalent of 24 pounds of nitrogen, 96 pounds of P_2O_5, and 96 pounds of K_2O per acre.

**Soluble magnesium applied as sulphate of potash-magnesia (Sul-Po-Mag) containing 18.5 per cent MgO and 21.5 per cent K_2O.

TABLE 5.—Effects of liming materials, magnesium and sulphur on yields of Ladino and Tensas red clover grown on nine Coastal Plain soils

Treatments*	Ruston** sl (6)	Eustis lfs (7)	Ruston sl (8)	Luverne fsl (9)	Ruston fsl (10)	Lakeland fs (11)	Ruston sl (12)	Orange-burg sl (13)	Kirvin fsl (14)
	Yield, grams per pot								
Oyster shells	21.3	33.3	24.3	23.5	20.4	20.2	19.1	23.0	29.1
Oyster shells + Mg and S***	24.5	39.8	33.9	37.7	38.8	51.4	41.3	45.1	51.9
Oyster shells + $MgNO_3$	23.3	35.5	24.3	24.2	20.7	21.3	18.8	21.9	29.5
Oyster shells + $CaSO_3$	23.4	35.6	31.0	35.8	37.3	44.9	38.6	45.4	51.4
Dolomitic Limestone	22.5	37.1	27.0	23.9	18.3	18.9	17.1	18.5	25.9
Dolomitic Limestone + $CaSO_4$	25.4	39.2	33.4	35.3	37.7	53.2	38.8	41.4	48.3
L.S.D. @ 5%	1.0	1.3	1.4	1.3	1.4	1.6	1.2	1.6	1.7
L.S.D. @ 1%	1.3	1.8	1.8	1.8	1.9	2.1	1.6	2.2	2.3

*All treatments received the equivalent of 36 pounds of nitrogen, 144 pounds of P_2O_5 and 144 pounds of K_2O per acre.

**Ladino clover grown on soil No. 6, red clover grown on soils Nos. 7 through 14.

***Magnesium and sulphur applied as sulphate of potash-magnesia (Sul-Po-Mag) containing 18.5 per cent MgO, 21.5 per cent K_2O and 22.7 per cent S.

TABLE 6.—Effects of liming materials, magnesium and sulphur on magnesium uptake by Ladino and Tensas red clover grown on nine Coastal Plain soils

Treatments*	Ruston** sl (6)	Eustis lfs (7)	Ruston sl (8)	Luverne fsl (9)	Ruston fsl (10)	Lakeland fs (11)	Ruston sl (12)	Orange-burg sl (13)	Kirvin fsl (14)
	Magnesium uptake, mg. per pot								
Oyster shells	91	72	93	89	66	51	71	104	110
Oyster shells + Mg and S***	118	133	156	164	142	147	185	240	235
Oyster shells + $MgNO_3$	114	131	113	114	84	74	81	118	121
Oyster shells + $CaSO_4$	110	80	116	126	96	84	126	185	244
Dolomitic Limestone	142	201	154	142	68	94	97	131	117
Dolomitic Limestone + $CaSO_4$	174	220	187	221	220	301	268	356	289

*All treatments received the equivalent of 36 pounds of nitrogen, 144 pounds of P_2O_5, and 144 pounds of K_2O per acre.

**Ladino clover grown on soil No. 6, red clover grown on soils Nos. 7 through 14.

***Magnesium and sulphur applied as sulphate of potash-magnesia (Sul-Po-Mag) containing 18.5 per cent MgO, 21.5 per cent K_2O

Effects of Magnesium and Sulphur on Yield and Nutrient Uptake

Since apparent responses to added magnesium appeared to be associated with sources of magnesium and sources of phosphorus containing sulphur, an experiment was designed to determine effects of magnesium and sulphur, applied separately and in combination, on yield and nutrient uptake by clover. Treatments used and yield data are presented in Table 5. On three soils, Ruston sandy loam, Eustis loamy fine sand, and Ruston sandy loam (soils 6, 7 and 8), higher clover yields resulted when dolomitic limestone was used than when oyster shells were employed. Clover showed favorable responses to magnesium on these soils. Yield increases were not obtained from the application of dolomitic limestone on Luverne fine sandy loam, Ruston fine sandy loam, Lakeland fine sand, Ruston sandy loam, Orangeburg sandy loam, and Kirvin fine sandy loam (soils 9, 10, 11, 12, 13, 14). Soil analysis data presented in Table 1 indicate that the magnesium contents of Orangeburg and Kirvin soils were relatively high; consequently, a response to supplementary magnesium was not expected. On Luverne fine sandy loam, Ruston fine sandy loam, Lakeland fine sand, and Ruston sandy loam (soils 9, 10, 11, 12), the magnesium levels were relatively low and yield responses to added magnesium were expected, but these responses were not obtained. When calcium sulphate was used with dolomitic limestone, significant increases in yield of clover were obtained on all soils studied. The data in Tables 6, 7 and 8 show that the uptake of magnesium, phosphorus and sulphur were also increased when calcium sulphate was used with dolomitic limestone. On nine Coastal Plain soils listed in Table 5, clover yields were increased approximately 60 per cent when calcium sulphate was added. Chemical analysis of plant tissue indicates that magnesium and phosphorus uptake were increased 95 and 62 per cent respectively from the addition of calcium sulphate (Figure 3). This indicates that sulphur present in calcium sulphate increased the availability of magnesium from dolomitic limestone and, directly or indirectly, effected an increase in the uptake of phosphorus.

On Ruston sandy loam and Eustis loamy fine sand (soils 6 and 7) listed in Table 5, the yields resulting from treatments that contained either magnesium nitrate or calcium sulphate with oyster shells were not significantly different. However, these treatments produced higher yields of clover than the treatments which did not contain magnesium or sulphur. Significantly higher yields of clover were obtained from applications of sulphate of potash-magnesia. When oyster shells served as the liming material, significantly higher yields of clover were obtained from treatments containing sulphur on Ruston sandy loam, Luverne fine sandy loam, Ruston fine sandy loam, Lakeland fine sand and Ruston sandy loam (soils 8, 9, 10, 11 and 12). Further increases in yield of clover were obtained when both magnesium and sulphur were included in the fertilizer treatments.

TABLE 7.—Effects of liming materials, magnesium and sulphur on phosphorus uptake by Ladino and Tensas red clover grown on nine Coastal Plain soils

Treatments*	Ruston** sl (6)	Eustis lfs (7)	Ruston sl (8)	Luverne fsl (9)	Ruston fsl (10)	Lakeland fs (11)	Ruston sl (12)	Orange-burg sl (13)	Kirvin fsl (14)
	Phosphorus uptake, mg. per pot								
Oyster shells	65	124	82	57	54	40	47	60	57
Oyster shells + Mg and S***	74	151	131	86	107	133	106	123	103
Oyster shells + $MgNO_3$	75	135	84	59	57	41	49	63	60
Oyster shells + $CaSO_4$	69	135	122	84	101	114	98	120	106
Dolomitic Limestone	70	142	107	60	52	37	47	50	53
Dolomitic Limestone + $CaSO_4$	76	153	141	85	104	134	105	110	102

*All treatments received the equivalent of 36 pounds of nitrogen, 144 pounds of P_2O_5 and 144 pounds of K_2O per acre.

**Ladino clover grown on soil No. 6, red clover grown on soils Nos. 7 through 14.

***Magnesium and sulphur applied as sulphate of potash-magnesia (Sul-Po-Mag) containing 18.5 per cent MgO, 21.5 per cent K_2O and 22.7 per cent S.

TABLE 8.—Effects of liming materials, magnesium and sulphur on sulphur uptake by Ladino and Tensas red clover grown on nine Coastal Plain soils

Treatments*	Ruston** sl (6)	Eustis lfs (7)	Ruston sl (8)	Luverne fsl (9)	Ruston fsl (10)	Lakeland fs (11)	Ruston sl (12)	Orange-burg sl (13)	Kirvin fsl (14)
	Sulphur uptake, mg. per acre								
Oyster shells	31	43	26	25	23	12	20	22	27
Oyster shells + Mg and S***	52	74	48	54	60	78	67	64	70
Oyster shells + $MgNO_3$	34	40	24	21	23	15	15	23	26
Oyster shells + $CaSO_4$	48	73	54	51	56	69	65	61	69
Dolomitic Limestone	34	40	30	25	22	11	16	14	26
Dolomitic Limestone + $CaSO_4$	50	73	58	51	65	74	63	67	66

*All treatments received the equivalent of 36 pounds of nitrogen, 144 pounds of P_2O_5 and 144 pounds of K_2O per acre.

**Ladino clover grown on soil No. 6, red clover grown on soils Nos. 7 through 14.

***Magnesium and sulphur applied as sulphate of potash-magnesia (Sul-Po-Mag) containing 18.5 per cent MgO, and 21.5 per cent K_2O and 22.7 per cent S.

On Orangeburg sandy loam and Kirvin fine sandy loam, significant increases in clover yields were obtained from the treatments containing sulphur. There were no differences in yield between treatments containing calcium sulphate and those containing sulphate of potash-magnesia. Clover responded to sulphur but failed to exhibit a significant response to magnesium on Orangeburg sandy loam and Kirvin fine sandy loam.

The data presented in Figure 4 represent a summary of yield and nutrient uptake of clover grown on Ruston sl, (soils 6, 8, and 12), Eustis lfs (soil 7), Luverne fsl (soil 9), Ruston fsl (soil 10), and Lakeland fs (soil 11).

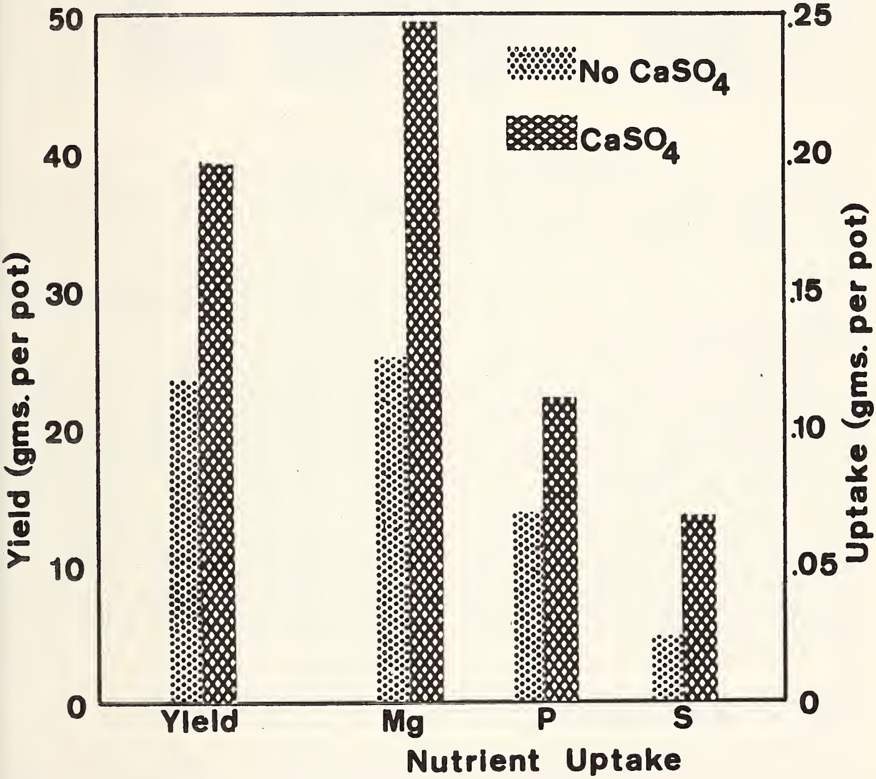

FIGURE 3.—Effects of calcium sulphate and dolomitic limestone on yield of clover and plant nutrient uptake (Nine soils listed in Table 5).

The addition of soluble magnesium as magnesium nitrate failed to significantly increase clover yields. Data on plant composition indicated larger amounts of magnesium were present in the plant tissue when this soluble source was used, but the uptake of phosphorus was not influenced to a noticeable degree by the magnesium treatment. Additions of sulphur as calcium sulphate had a marked effect on both

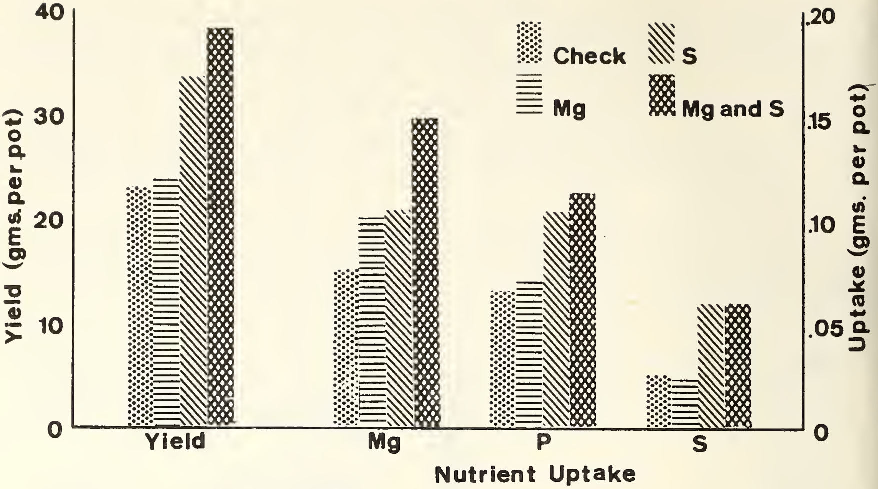

FIGURE 4—Effects of magnesium and sulphur additions on yield of clover and plant nutrient uptake when oyster shells were used as the liming material. (Soils 6 through 12 listed in Table 5).

yield and chemical composition of the clover. A highly significant increase, amounting to 52.1 per cent in growth, was obtained when calcium sulphate was applied.

Clover growing on soils that received calcium sulphate absorbed considerably more magnesium, phosphorus, and sulphur than did clover growing on the untreated soil. The amount of magnesium and phosphorus absorbed was increased 38.2 and 54.0 per cent respectively. This indicates that sulphur had an effect in increasing the availability and subsequent absorption of native soil magnesium. The data also indicates that sulphur had a favorable influence on increasing the absorption of phosphorus. The highest yield shown in Figure 4 occurred on soils receiving both magnesium and sulphur supplied as sulphate of potash-magnesia.

Response to Magnesium

Yield response, resulting from the combined application of a soluble source of magnesium and sulphur in comparison with the addition of sulphur alone, was attributed to magnesium. Yield data presented in Tables 2 and 5, coupled with chemical soil properties included in Table 1, indicate that yield response to magnesium was obtained on soils in which magnesium represented less than 10 per cent of the total cation exchange capacity and contained less than 55 ppm. of extractable magnesium. The yield response of clover, however, was influenced by the presence of sulphur in the fertilizer. Responses of clover to magnesium were not obtained on Orangeburg sandy loam and Kirvin fine sandy loam. These two soils contained 60 and 55 ppm. of extractable magnesium respectively, and 10 per cent of the exchange capacity was represented by magnesium.

An increase in yield of Ladino clover due to the application of magnesium was obtained on Ruston sandy loam (soil 6). This soil contained 52 ppm. of extractable magnesium, and 6.7 per cent of the exchange capacity was represented by magnesium.

The results of these greenhouse experiments indicate that on the sandy soils of the Coastal Plain areas of Louisiana a response of clover to magnesium could be expected if the amount of extractable or "available" magnesium is less than 55 ppm. and if magnesium represents less than 10 per cent of the total cation exchange capacity. The yield response of clover to supplementary magnesium is governed in part by the per cent magnesium saturation of the cation exchange complex of the soil and the presence of sulphates in the fertilizer used.

Summary and Conclusions

A greenhouse study was conducted to determine the effects of sources of liming materials, magnesium, and sulphur on the growth of Ladino clover and Tensas red clover. Soils from the Coastal Plain areas of Louisiana were used in this study.

Significant responses to magnesium and increases in magnesium and phosphorus uptake by clover were associated with the presence of sulphur in the fertilizer treatments. Yield responses were attributed to sulphur contained in ordinary superphosphate and sulphur supplied by sulphate of potash-magnesia. The results indicate that the response of clover to magnesium was conditioned by the presence of sulphur in the fertilizer.

Significant increases in yield of clover were obtained when sulphur as calcium sulphate was used with dolomitic limestone. The uptake of magnesium, phosphorus, and sulphur was also increased when calcium sulphate was used with dolomitic limestone. Sulphur in calcium sulphate increased the availability of magnesium from dolomitic limestone and effected an increase in the uptake of phosphorus.

Applications of sulphur as calcium sulphate significantly increased the yield of clover when oyster shells were used. Increases in the uptake of magnesium and phosphorus were also obtained when calcium sulphate was used with oyster shells. This indicates that sulphur had an effect in increasing the availability and subsequent absorption of native soil magnesium. The highest yield of clover occurred on soils receiving both magnesium and sulphur supplied as sulphate of potash-magnesia. The additional yield increase from the combined application of soluble magnesium and sulphur in comparison with the addition of sulphur alone was attributed to magnesium.

The results of these greenhouse experiments indicate that, on the sandy soils of the Coastal Plain areas of Louisiana, response of Ladino

and Tensas red clovers to magnesium could be expected if the amount of dilute acid extractable or exchangeable magnesium was less than 55 ppm. or if magnesium represents less than 10 per cent of the total cation exchange capacity of the soil.

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