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Liming of alfalfa in a greenhouse study

N. S. Loganathan

To the Graduate Council:

I am submitting herewith a thesis written by N. S. Loganathan entitled "Liming of alfalfa in a greenhouse study." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

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We have read this thesis and recommend its acceptance:

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Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

August 15, 1961

To the Graduate Council:

I am submitting a thesis written by N. S. Loganathan entitled "Liming of Alfalfa in a Greenhouse Study." I recommend that it be accepted for nine quarter hours credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

O. H. Long

Major Professor

We have read this thesis and recommend its acceptance:

Horace C. Smith Jr.

Robert L. Dotson

Accepted for the Council:

W. E. Spivey

Dean of the Graduate School

LIMING OF ALFALFA IN A GREENHOUSE STUDY

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

N. S. Loganathan

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CHAPTER I

INTRODUCTION

The use of agricultural lime has been recognized down through the ages as a practice that is basic to good soil management in humid regions. The effects of liming are a complex of many contributing physical, chemical, microbiological and physiological factors. Its direct function is to correct soil acidity, improve soil structure and create an environment suitable to the growth and development of plants. Liming enhances the availability and plant uptake of elements such as nitrogen, phosphorus, molybdenum, calcium, and magnesium. At the same time it drastically reduces the concentration of iron, aluminum and manganese, which under very acid conditions are apt to be present in toxic quantities. In at least some soils, it enhances the availability of potassium. Lime stimulates the general-purpose, heterotrophic soil organisms, thereby increasing their activity on organic matter and the releasing of nitrogen. This favors the formation of humus and also encourages the elimination of certain intermediate products that might be toxic to higher plants. Within the plant, too, lime performs many functions. Calcium is essential for the growth of the meristems, the development and functioning of root tips, and for certain enzymatic reactions involved in respiration.

The uptake of nutrients by roots of plants from the soil medium is a complex physiological process, the rate of which is greatly influenced by environmental factors. Greenhouse experiments have several advantages in this regard, most important of which is the control of numerous environmental factors. It is also possible under greenhouse conditions to design experiments to include a large number of treatments and a variety of soils; they can be carried out at any time of the year irrespective of the season. Furthermore, investigations of a fundamental nature such as soil-plant relationships, can be made in a greenhouse without the involvement of elaborate field studies, high cost and undue labor. At the same time, they can serve as pilot projects for appropriate field studies in the future.

The influence of lime on acid soils in promoting the growth, yield and uptake of nutrients is one of fundamental importance and immediate concern to the agronomist.

Lime-fertilizer experiments in the greenhouse involving the use of calcium, phosphorus and potassium on acid infertile soils are therefore very important in giving some indication as to the wise use of these nutrients. Since root development of crops in acid soils is very much dependent on the soil condition, its lime content and the nature of its zone of penetration, the placement of lime as an additional factor in the balance of fertilization assumes relatively great importance.

This work was undertaken with the following objectives in view:

1. To study the influence of liming and fertilization of an acid soil on growth, yield, root development and uptake of various cations by plants.

2. To study the influence of placement of lime in different layers of the soil on the above factors.

Hartsells loam was the soil used for the study. It was low in all nutrients. Alfalfa was used as the indicator plant because it is known to be sensitive to soil acidity.

CHAPTER II

REVIEW OF LITERATURE

A large number of greenhouse and field experiments have been conducted all over the United States and many other parts of the world to investigate the effects of liming and fertilizing acid soils on the yield and nutrient content of different crops.

Comprehensive reviews of the earlier works have been made by Truog (40) and more recently by Pearson (24). No attempt will be made to review the entire literature on this subject, but a few publications that have a direct bearing on the design and interpretation of findings of this study are mentioned. Attention is drawn to two aspects of this experiment, *viz.*, liming and its effect on soil reaction, nutrient availability and plant growth and the influence of placement of lime on the above factors.

Thorp and Hobbs (38) reported that liming of acid soils with adequate amounts of other nutrients resulted in significant increases in yields of the first and third cuttings of alfalfa over those obtained where no lime was added. However, no significant differences in yields were obtained with various rates of liming, although they increased consistently with each addition of lime.

Similarly, Sewell and Latshaw (32) found that increasing the amount of lime at rates which raised the soil pH from 5.0 to 6.4 with increasing amounts of phosphorus (0, 150, 300 and 450 pounds of P_2O_5 per acre) increased the total yield and also the phosphorous content of alfalfa forage grown on normal acidic soils of eastern Kansas. It was also noted that lime alone had little effect on the plant content of phosphorus.

Lawton and Davis (15) studied the effects of liming strongly acid soils on the growth and absorption of soil and fertilizer phosphorus by field beans. They reported that the yield of field beans (oven-dried weight) was markedly increased with progressive increases in lime applications up to 12 tons of calcium carbonate per acre. They also reported that an increase in the rate of lime application progressively decreased the phosphorous content of beans on non-phosphated soil.

Results obtained by Albrecht and Klemme (2) from field experiments indicated that an application of superphosphate alone increased the yield of alfalfa by 16.6 per cent, whereas limestone and superphosphate together increased the yield 82.9 per cent over the control. They also reported that applications of limestone and superphosphate to mineral soils approximately doubled the phosphorous content of lespedeza forage over that contained in plants from soils receiving phosphate alone.

Results by Moschler _et_. _al_. (23) showed that lime was indispensable to growth, yield and longevity of alfalfa. Each addition of lime generally resulted in increased yields, although the yields were not significantly higher with the higher rates of lime. At the higher lime rates the color of alfalfa was dark green as contrasted with a lighter yellowish green at lower rates. The calcium and magnesium contents of the plants increased with the increasing rates of liming. The root system of plants in limed soil was heavier, larger and of greater proliferation in the surface soil, but there was no increase in the depth to which the tap root extended.

Robertson et. al. (29) found that less fertilizer phosphorus was required to give maximum yields of oats and corn on limed than on unlimed soils.

The beneficial effects of liming and phosphating acid soils were also shown by Chronister (7), Ewing (10) and Pendergrass (27). They found that yields of crimson clover and corn were greatly increased by applications of lime and phosphorus.

Dawson (8) reported that growth and yield response of alfalfa generally increased with increasing base saturation levels of four contrasting soils, which was attributed to the direct or indirect effects of lime. He found that soil pH readings at the same base saturation levels varied considerably with different soils and that the pattern of alfalfa response to lime also varied. He also pointed out that additional calcium supplied to isolated root sections independent of the soil increased alfalfa yields significantly, while it decreased the maganese content of the foliage.

Albrecht (1) and Horner (12) concluded that the principal beneficial effect from liming acid soils resulted from an increase in calcium as nutrient for pasture plants.

Allaway (3) and Mehlich et. al. (19, 21, 22) reported that the availability of calcium increased with increasing degrees of calcium saturation of clays.

Chandler (6) illustrated that in unlimed soils a larger percentage of accumulated phosphorus was in less available forms, associated with free sesquioxides. His results showed that phosphorous absorption by clay separates of several latosols decreased with increasing degrees of calcium saturation before removal of the sesquioxides, but was influenced very little after removal of free R_2O_3.

MacLean and Cook (17) reported that liming soils up to pH 7.5 increased the yields of alfalfa on five out of six soils studies, when no phosphorous application was made. When phosphorus was applied the optimum reaction for alfalfa was reached in most instances at a pH of 6.5 to 7.0. An application of phosphorus resulted in an appreciable increase in the yield of alfalfa. Native and applied phosphorus seemed to be more available to alfalfa at a pH slightly above the neutral point than at lower pH levels.

Peech and Bradfield (26) reviewed the literature on the effect of calcium and magnesium on soil potassium and its uptake by plants. They reported that an increase in the degree of calcium saturation favored the absorption of potassium from solution and its neutral salts. The influence of magnesium on the clay upon the absorption of potassium from potassium chloride was similar to that of calcium.

Stubblefield and DeTurk (37), summarizing the results of experiments conducted over a period of four years in Illinois, concluded that liming of soils is generally reflected in an increased percentage of calcium in plants. But as phosphorus was converted into living tissues and became part of the organic plant body, an increase in uptake of this element was accompanied by a corresponding increase in growth, and so the percentage of phosphorus was not influenced by additions of phosphatic fertilizers.

Smith and Hester (34) found that the liming of an acid Putnam silt loam, low in calcium, failed to increase the calcium content of soybeans, but produced a significant increase in its nitrogen and phosphorous content.

Bear and Wallace (4) reported that an annual topdressing of 1000 pounds of calcium carbonate per acre resulted in a definite increase in the yield of alfalfa over that obtained on the unlimed soil. This experiment was conducted on a sandy soil.

From the results of experiments conducted in Kentucky, Ohio, Illinois and Alabama with cotton, corn, oats, wheat, clover and timothy, which included treatments without lime and fertilizer, with fertilizer alone and with lime and fertilizer, Pearson (24) illustrated that the relative efficiency of fertilizer without lime in Kentucky was only one-half of what it was when used with lime. Similarly, the data from experiments in Ohio and other places showed very low relative efficiencies for fertilizer without lime. In the case of corn, oats and wheat the use of lime improved fertilizer effectiveness nearly four-fold and with clover and timothy the effect was much greater.

Rogers (30) reported a marked improvement in over-all efficiency in utilization of applied potassium by peanuts on a typical soil of the South Eastern Coastal Plain, as a result of liming. With runner peanuts the efficiency was increased progressively from 42 per cent in unlimed soil to as high as 85 per cent at the 8,000-pound rate of liming. An even more striking effect of liming was found with Spanish peanuts. Here the efficiency of potassium uptake was increased from 27 per cent to 73 per cent by an application of 3,000 pounds of limestone.

Griffiths (11) reported that magnesian limestone applied to grassland which had been frequently and heavily nitrated increased the yield and magnesium content of forage. Magnesium applied in the form of magnesite or magnesium sulfate was not as effective as that applied in the form of dolomite.

Horner (12) studied the relation of total calcium supply and the degree of saturation of a collodial clay by calcium to the growth, nodulation and chemical composition of soybeans. He found that growth, nodulation, nitrogen fixation and calcium absorption increased with higher calcium levels. The growth and nitrogen-fixing activities of legumes were closely related to the amount of calcium in the plant.

In an experiment on the calcium and magnesium requirements of soybeans, Welch and Nelson (41) found that calcitic lime increased the yield of this crop. They reported that the first increment, which resulted in calcium saturations of 19, 31 and 27 per cent in Hyde, Craven and Bladen soils, was generally sufficient. There was some indication, however, that a higher base saturation was required with dolomitic limestone and that yield was closely related to calcium supply. Yield increases were obtained from magnesium sulfate in the treatment where calcium was applied at a higher rate. They concluded that the amount of calcium supplied was important and that soybean yields were rather closely related to the degree of calcium saturation, regardless of the source.

Most investigations on soil acidity and liming have been concerned with plow or surface layer only. Studies and experiments on placement of lime are rather limited.

Longenecker and Merkle (16) studied the influence of placement of lime on crimson clover in pots treated with lime in different soil layers, and reported that liming the top 6 inches gave the highest yields. However, there was not a marked difference in yield from the top 3-inch liming, though the deeper and better root development resulting from 6-inch liming would undoubtedly enable the crop to endure drought and utilize soil resources better under field conditions. They concluded that primary roots extended through zones of unfavorable conditions, but fibrous root development was restricted to regions of high fertility. They supported the concept that for reasonably rapid results lime compounds should be thoroughly mixed into the entire soil in which roots were expected to develop.

Kohnke and Bertrand (14) conducted experiments on fertilizing the subsoil of several Indiana soils and reported that the growth of corn roots greatly increased as a result of subsoil fertilization and that the subsoiled areas generally contained more moisture than the untreated plots. Yield increases from subsoil fertilization were substantial in many cases but not consistent.

In experiments with tomatoes, Tiedjens (39) found that placement of lime and fertilizer to depths of 15 to 18 inches definitely promoted better root development at greater depths and concluded that at these lower levels phosphorus was the limiting factor.

A field study on the effect of shattering the subsoil was made by Woodruff and Smith (42). Their results indicated that the lack of lime in the subsoil was of greater significance than the poor physical condition of the soil. They reported that subsoil shattering with deep placement of lime and fertilizer appeared to improve the growth and rooting of sweet clover and corn. They concluded that subsoil shattering with deep placement of lime and fertilizer appeared to be a solution to the problem of growing corn on claypan soils.

Investigations over a five year period on deep plowing, subsoiling, and deep incorporation of lime and fertilizer were conducted on a strongly acid and tight subsoil by Engelbert and Truog (9). Subsoil treatments included tillage only, tillage with liming, and tillage with liming and fertilizing. They observed that deeper root penetration of alfalfa was promoted by subsoil liming and fertilizing, but not by subsoiling alone. Subsoil liming and fertilizing helped materially in establishing alfalfa during a dry year. Second-year and especially third- and fourth- year hay yields appeared to be increased by subsoil liming and fertilizing but were not increased by subsoil treatment where the fertilizer was omitted. The potassium content of the alfalfa from subsoil fertilized plots was higher in dry years. They concluded that in no year were the yields of corn and oats increased by deeper plowing, liming and fertilizing, although increased vigor was noted in some years.

Younts and York (43) studied the effects of distributing lime and fertilizer at specified depths in soils down to 24 inches on the yields and nutrient content of corn and crimson clover. They reported that dry matter yields of corn were unaffected by the depth of lime and fertilizer distribution. Crimson clover yields, on the other hand, were increased somewhat where the soil was limed and fertilized to a depth of 24 inches, and these yields could be related to the increased absorption of potassium with deeper placement. No other effect of lime and fertilizer distribution upon nutrient content of the plants was observed.

Jamison et. al. (13) reviewed investigations on subsoiling accompanied by liming and fertilizing in the Midwest. Corn, oats, sweet clover and alfalfa were used as the test crops. The results showed that the benefits from deep tillage and fertilization of the above crops were both variable and relatively small. Considering the expense, the workers agreed that it was doubtful if subsoiling could be justified in the North Central States, particularly when compared with good fertility and management practices in the plow layer.

Pohlman (28) conducted an experiment on the effect of liming various soil layers of a strongly acid soil on yield, root development and nodulation of alfalfa. He reported that maximum yields were obtained where both the 0-8 and the 8-16 inch layers were limed approximately to neutrality. He observed that a marked downward movement of lime occurred not only from one layer to another but also within the layer receiving the lime, the difference in reaction between the 0-3 and the 6-8 inch sections after 9 years being over 1 pH unit. Root distribution was markedly affected by liming the subsurface horizons. Liming the 18-24 inch layer to about neutrality resulted in an increase of 50 per cent in the proportion of the total root growth found in this layer. Moreover, the fibrous roots were largely concentrated in this layer. The nodules on the roots were largely concentrated in the layer receiving the high lime treatment, irrespective of whether this was the 8-16 or the 16-24 inch layer.

CHAPTER III

MATERIALS AND METHODS

The soil used in this experiment was Hartsells loam. Some of the chemical characteristics of this soil are given in Table I. The liming material used was dolomitic limestone, 95 per cent calcium carbonate equivalence, ground to pass through a 100-mesh sieve. The nitrogen, phosphorous, potassium mixture contained nitrogen in the form of ammonium nitrate, phosphorus in the form of monocalcium phosphate, and potassium in the form of potassium sulfate. Eight kilograms of the treated soil was placed in two-gallon glazed pots on January 19, 1961 and was watered and seeded to alfalfa on January 27, 1961. Details of the procedure followed in the greenhouse and laboratory phases are given below.

I. GREENHOUSE EXPERIMENT

The experiment consisted of nine treatments each of which was replicated three times. The liming rates were no lime, limed to 100 per cent base saturation, and limed to 150 per cent base saturation. There were three placements of lime: (1) liming of the 8 kg. of soil to full depth, (2) liming of the upper layer (4 inches or 4 kg.), and (3) liming of the lower layer.

Liming 8 kilograms of soil to 100 per cent base saturation required 28.88 grams of dolomite (equivalent to 6860 pounds per acre, or two million pounds of soil), and liming to 150 per cent base saturation

Table 1.--Some chemical properties of Hartsells loam used in lime study on alfalfa

pH	Organic Matter Content	Exchangeable, me/100 gm.				Base Saturation
		K	Ca	Mg	C. E. C.	
	%					%
4.7 - 4.8	2.57	0.13	0.80	0.21	8.00	14.3

required 45.73 grams of dolomite (equivalent to 10, 860 pounds per acre). Where only the upper or lower layer of soil was limed, one-half the amounts mentioned above was used. The fertilizer mixture was applied at a rate of 30-400-400 (N-P_2O_5-K_2O) per acre and mixed with the soil to full depth in seven treatments; two treatments were not fertilized.

The pots were filled with the treated soils on January 19, 1961, and watered the next day.

About 40 inoculated alfalfa seeds of the Buffalo variety were planted in each pot on January 27, 1961. Before planting, the top ¼-inch of soil was treated with PCNB fungicide as a preventive measure against "damping-off" disease. After stand establishment, the pots were watered uniformly every two or three days.

The first crop was harvested 15 weeks after seeding on May 16, 1961. The harvested plants from each pot were placed in separate paper bags, dried in an oven at 70^{o} C, and the weights recorded. The dried plant material was ground in a Wiley mill and stored in glass bottles for chemical analysis.

Two weeks after the first cutting, the plants were treated with Diazinon to control aphids, which gave complete control.

The second cutting was made on June 12, 1961, 4 weeks after the first cutting. This cutting was handled in the same way as the first cutting.

Immediately after the second cutting the soil was removed from the pots and the roots were carefully separated out by washing. The roots in the upper layer (4 inches) of soil were collected separately from the roots in the lower layer. At the same time, soil samples were taken from the upper and lower layers of soil for pH and available phosphorous and potassium determinations. The roots thus collected were put into separate paper bags, dried in an oven at 70° C, and the weights recorded.

II. LABORATORY STUDIES

The laboratory studies consisted of soil studies and the analysis of plant materials.

Soil tests.

Soil tests were made to determine the changes in pH, phosphorous and potassium levels brought about by liming and fertilization. Soil reaction (pH) was measured potentiometrically with a Beckman Zeromatic glass electrode pH meter. Determinations for phosphorus and potassium were made on a soil solution after extracting with 0.05 N H_2SO_4 containing 1 per cent $(NH_4)_2SO_4$; the soil-solution ratio was 1:4. Phosphorus was determined colorimetrically, while potassium was determined in a flame spectrophotometer.

Plant analysis.

The plant material of each cutting from all pots was analyzed for its content of phosphorus, potassium, calcium and magnesium. Phosphorus was determined by the method as described by Sterges et al. (36); potassium, calcium and magnesium were determined by the method as described by Shaw and Veal (33).

CHAPTER IV

RESULTS

I. YIELDS

The first- and second-cutting yields of alfalfa forage are presented in Tables 2 and 3; the total yields of the two cuttings are presented in Table 4. These data were subjected to statistical analysis following the procedure as outlined by Snedecor (35).

Forage yields

The lowest yield of alfalfa forage was obtained on the no-lime, no-fertilizer treatment. Total yield of the 2 cuttings averaged 0.18 gram. The highest yields were recorded in both the treatments where the soils were limed to full depth at 100 and 150 per cent base saturation. On both these treatments the total yield of the 2 cuttings was 12.24 grams.

A statistical analysis revealed highly significant differences in yield between the limed and unlimed soil and among lime placements. These growth differences are illustrated in Figure 1. Forage yields were decidedly inferior where only the bottom layer of soil (4- to 8-inch depth) was limed.

The average yields of the two treatments which were not limed were 0.18 gm. and 0.82 gm., whereas the limed-unfertilized treatment produced a yield which was more than 8 times the unlimed-fertilized treatment. The highest yields were obtained where the soil was fertilized and limed to full depth; the average yield where the soil was limed to 100 per cent base saturation (12.24 gm.) was the same as it was where it

Table 2.--First cutting yields of alfalfa on Hartsells loam in greenhouse (May 16, 1961)

(Oven-dry weight of forage in grams per 8 kg. of soil in 2-gallon glazed pots)

Tmt. No.	Soil Treatment	Replication 1	2	3	Av. of 3 Reps.
1	No lime, no fertilizer	0.07	0.12	0.07	0.09
2	No lime, fertilized	0.23	1.03	0.54	0.60
3	Limed entire 8 kg. to 150% b.s., no fert.	3.21	5.16	4.11	4.16
4	Limed entire 8 kg. to 100% b.s., fertilized	7.35	7.60	7.53	7.49
5	Limed top 4 kg. to 100% b.s., fertilized	7.33	7.08	7.27	7.23
6	Limed bottom 4 kg. to 100% b.s., fertilized	5.21	5.02	5.31	5.18
7	Limed entire 8 kg. to 150% b.s., fertilized	8.96	7.58	7.14	7.89
8	Limed top 4 kg. to 150% b.s., fertilized	6.84	8.45	6.68	7.32
9	Limed bottom 4 kg. to 150% b.s., fertilized	4.90	5.42	5.67	5.33

Table 3.--Second cutting yields of alfalfa on Hartsells loam in greenhouse (June 12, 1961)

(Oven-dry weight of forage in grams per 8 kg. of soil in 2-gallon glazed pots)

Tmt. No.	Soil Treatment	Replication 1	2	3	Av. of 3 Reps.
1	No lime, no fertilizer	0.09	0.11	0.09	0.10
2	No lime, fertilized	0.19	0.28	0.20	0.22
3	Limed entire 8 kg. to 150% b.s., no fert.	2.26	2.70	2.61	2.52
4	Limed entire 8 kg. to 100% b.s.,fertilized	4.60	4.87	4.77	4.75
5	Limed top 4 kg. to 100% b.s.,fertilized	4.52	4.30	4.60	4.47
6	Limed bottom 4 kg. to 100% b.s.,fertilized	3.78	3.50	3.69	3.66
7	Limed entire 8 kg. to 150% b.s.,fertilized	4.61	4.22	4.20	4.34
8	Limed top 4 kg. to 150% b.s.,fertilized	4.30	4.79	4.21	4.43
9	Limed bottom 4 kg. to 150% b.s.,fertilized	3.96	4.12	3.83	3.97

Table 4.--Total yield of 2 cuttings of alfalfa on Hartsells loam in greenhouse, 1961

(Oven-dry weight of forage in grams per 8 kg. of soil in 2-gallon glazed pots--summarized from Tables 2 and 3)

Tmt. No.	Soil Treatment	Replication 1	Replication 2	Replication 3	Av. of 3 Reps.
1	No lime, no fertilizer	0.16	0.23	0.16	0.18
2	No lime, fertilized	0.42	1.31	0.74	0.82
3	Limed entire 8 kg. to 150% b.s., no fert.	5.47	7.86	6.72	6.68
4	Limed entire 8 kg.to 100% b.s.,,fertilized	11.95	12.47	12.30	12.24
5	Limed top 4 kg. to 100% b.s., fertilized	11.85	11.38	11.87	11.70
6	Limed bottom 4 kg. to 100% b.s.,fertilized	8.99	8.52	9.00	8.84
7	Limed entire 8 kg. to 150% b.s.,fertilized	13.57	11.80	11.34	12.24
8	Limed top 4 kg. to 150% b.s., fertilized	11.14	13.24	10.89	11.76
9	Limed bottom 4 kg. to 150% b.s.,fertilized	8.86	9.54	9.50	9.30

Rate of liming

100% = 10.93
150% = 11.10

L.S.D. (5%) = N. S.

Lime placement

Limed throughout	= 12.24
Limed top half	= 11.73
Limed bottom half	= 9.07
L. S. D. (5%)	= 1.03
(1%)	= 1.47

Analysis of Variance
(Treatments 4 - 9)

Source of Variation	D. F.	Sum of Squares	Mean Square	F Value
Treatments	5	35.0961	7.0192	10.85**
Rate of Liming	1	.1335	.1335	0.21
Lime Placement	2	34.7692	17.3846	28.42**
Rate x Placement	2	.1934	.0967	0.15
Replications	2	.3712	.1856	0.29
Error	10	6.4690	.6469	
Total	17	41.9363		

**Significant at the 1% level of probability.

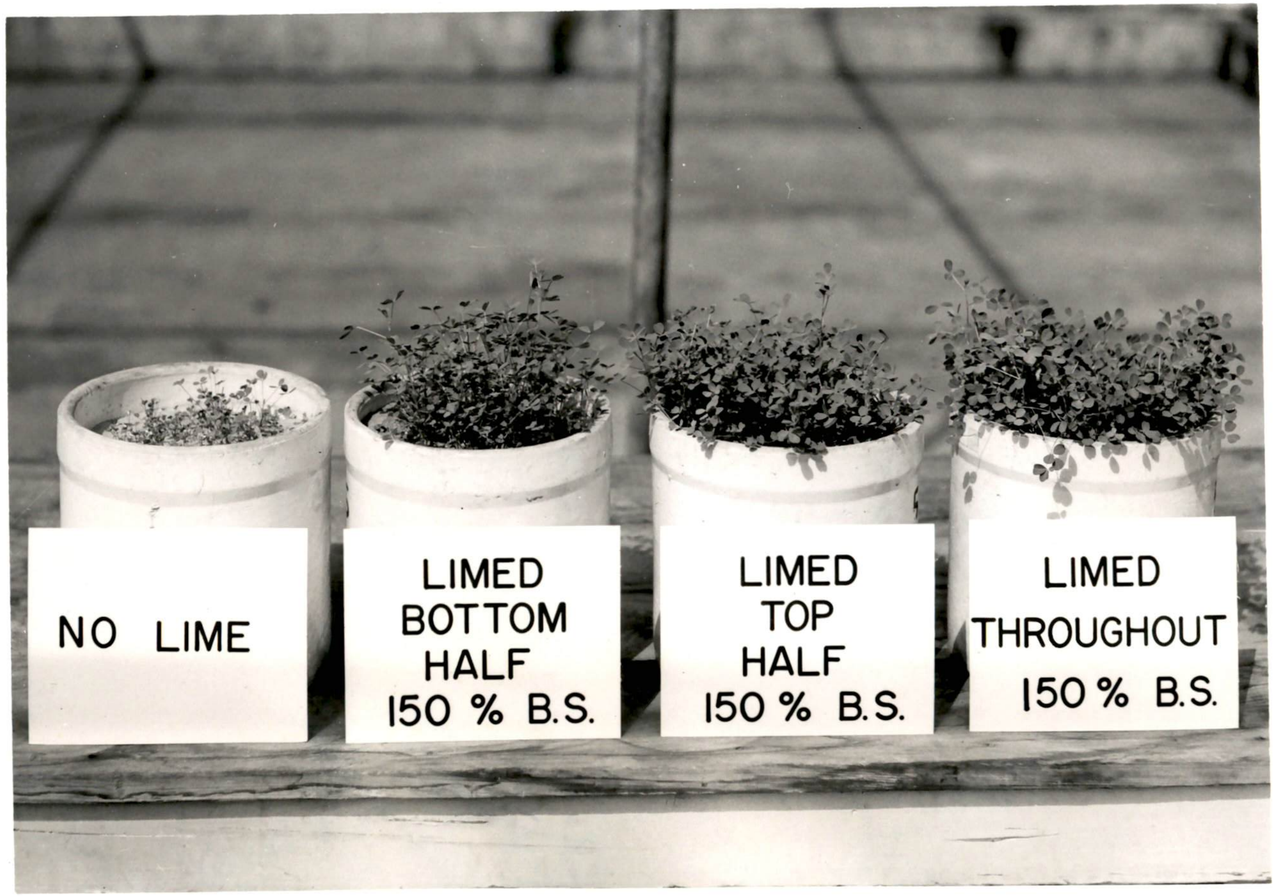

Figure 1.--Response of alfalfa to lime on a Hartsells loam soil (photographed March 29, 1961).

was limed to 150 per cent base saturation. Liming of the upper layer only resulted in an average yield of 11.73 gm. of forage for the two base saturations, but the liming of the lower layer only resulted in an average yield of only 9.07 gm. The statistical analysis reveals that there was no significant difference between the yields at the rates of liming, but that liming of the lower layer resulted in significantly lower yields than were obtained with liming of the upper layer on with liming to full depth.

Root yields

The root yields of alfalfa are shown in Tables 5 and 6; in Table 5 root weights in the upper and lower layers are shown separately, while these weights are combined in Table 6.

For the treatments as a whole about 72 per cent of the total root weight was found in the upper layer (0-4 inches) of the soil. This is not surprising, since the large fleshy portions of the taproots were found in this layer. The finer fibrous roots were largely confined to the lower layer (4-8 inches).

Like the top growth, the lowest average yield of roots was obtained in the unlimed and unfertilized treatment. The highest yield of roots was obtained in the treatment where the bottom layer was limed to 100 per cent base saturation and fertilized to full depth. The differences in yield between limed and unlimed treatments were significant; however, there was no significant difference in the yields among the limed-fertilized treatments, either for rate of liming or for placement of lime.

Table 5.--Root yields of alfalfa in upper and lower layers of soil, Hartsells loam, 1961

(Oven-dry weight of roots in grams per 8 kg. of soil in 2-gallon glazed pots)

Tmt. No.	Soil Treatment	Replication 1	2	3	Av. of 3 Reps.
	Upper 4 kg. of soil (0 - 4 inches)				
1	No lime, no fertilizer	0.41	0.48	0.33	0.41
2	No lime, fertilized	0.49	0.80	0.57	0.62
3	Limed entire 8 kg. to 150% b.s., no fert.	1.76	3.06	4.03	2.95
4	Limed entire 8 kg. to 100% b.s.,fertilized	6.59	6.60	10.69	7.96
5	Limed top 4 kg. to 100% b.s.,fertilized	6.12	6.05	7.62	6.60
6	Limed bottom 4 kg. to 100% b.s.,fertilized	7.57	7.47	7.60	7.55
7	Limed entire 8 kg. to 150% b.s.,fertilized	8.39	5.76	5.33	6.49
8	Limed top 4 kg. to 150% b.s., fertilized	6.49	6.80	5.99	6.43
9	Limed bottom 4 kg. to 150% b.s.,fertilized	6.66	5.99	7.32	6.66
	Lower 4 kg. of soil (4 - 8 inches)				
1	No lime, no fertilizer	0.26	0.31	0.22	0.26
2	No lime, fertilized	0.37	0.73	0.47	0.52
3	Limed entire 8 kg. to 150% b.s., no fert.	0.96	1.24	1.20	1.13
4	Limed entire 8 kg. to 100% b.s.,fertilized	2.59	2.03	3.20	2.61
5	Limed top 4 kg. to 100% b.s.,fertilized	1.92	2.16	2.74	2.27
6	Limed bottom 4 kg. to 100% b.s.,fertilized	3.69	3.34	3.61	3.55
7	Limed entire 8 kg. to 150% b.s.,fertilized	2.56	2.32	1.93	2.27
8	Limed top 4 kg. to 150% b.s., fertilized	1.89	3.42	2.01	2.44
9	Limed bottom 4 kg. to 150% b.s., fertilized	3.09	2.59	2.31	2.66

Table 6.--Total root yields of alfalfa on Hartsells loam in greenhouse, 1961

(Oven-dry weight of roots in grams per 8 kg. of soil in 2-gallon glazed pots--summarized from Table 5)

Tmt. No.	Soil Treatment	Replication 1	Replication 2	Replication 3	Av. of 3 Reps.
1	No lime, no fertilizer	0.67	0.79	0.55	0.67
2	No lime, fertilized	1.86	1.53	1.04	1.14
3	Limed entire 8 kg. to 150% b.s., no fert.	2.72	4.30	5.23	4.08
4	Limed entire 8 kg. to 100% b.s.,fertilized	9.18	8.63	13.89	10.57
5	Limed top 4 kg. to 100% b.s., fertilized	8.04	8.21	10.36	8.87
6	Limed bottom 4 kg. to 100% b.s.,fertilized	11.26	10.81	11.21	11.09
7	Limed entire 8 kg. to 150% b.s.,fertilized	10.95	8.08	7.26	8.76
8	Limed top 4 kg. to 150% b.s.,fertilized	8.38	10.22	8.00	8.87
9	Limed bottom 4 kg. to 150% b.s.,fertilized	9.75	8.58	9.63	9.32

Rate of Liming

100%	= 10.18
150%	= 8.98
L. S. D. (5%)	= N. S.

Lime Placement

Limed throughout	= 9.67
Limed top half	= 8.87
Limed bottom half	= 10.21
L. S. D. (5%)	= N. S.

Analysis of Variance (Treatments 4 - 9)

Source of Variation	D. F.	Sum of Squares	Mean Square	F Value
Treatments	5	15.0335	3.0067	1.05
Rate of Liming	1	6.4082	6.4082	2.25
Lime Placement	2	5.4384	2.7192	0.95
Rate x Placement	2	3.1869	1.5935	0.56
Replications	2	2.8243	1.4122	0.50
Error	10	28.5166	2.8517	
Total	17	46.3744		

II. MINERAL COMPOSITION OF THE FORAGE

Data showing the mineral composition of the forage produced on the various treatments are given in Tables 7 to 10. Table 7 contains the data with respect to phosphorous content, Table 8 with respect to potassium content, Table 9 with respect to calcium content, and Table 10 with respect to magnesium content. The important findings for each nutrient element are as follows:

Phosphorus. The average per cent phosphorus in the forage varied from 0.11 to 0.21 in the first cutting and from 0.17 to 0.38 in the second cutting. The lowest concentration was in the no-lime, no-fertilizer treatment, while the highest concentration was in the treatment where the soil was limed throughout to 150% base saturation. This was true for both cuttings. The phosphorous content on the average was higher in the treatments where the soil was fertilized and limed to 150% base saturation than it was where it was limed to 100 per cent base saturation. This was more pronounced in the second cutting. The phosphorous content of the plants showed some differences between the two cuttings, generally being higher in the second cutting than in the first.

Potassium. The potassium content of the forage (Table 8) ranged from 1.35 to 3.23 per cent in the first cutting and 2.23 to 4.30 per cent in the second cutting. In both cuttings, the lowest content was in the treatment where the soil was limed to 150 per cent saturation, but not fertilized. However, the highest content (3.23 per cent) in the first cutting was recorded for the treatment where the soil was not limed but

Table 7.--Phosphorous (P) content of alfalfa forage on Hartsells loam

(Oven-dry basis)

Tmt. No.	Soil Treatment	Replication 1	2	3	Av. of 3 Reps.
		%	%	%	%
	First Cutting (5-16-61)				
1	No lime, no fertilizer	0.15	0.10	0.08	0.11
2	No lime, fertilized	- -	0.24	0.17	0.21
3	Limed entire 8 kg. to 150% b.s., no fert.	0.15	0.13	0.12	0.13
4	Limed entire 8 kg. to 100% b.s.,fertilized	0.17	0.19	0.16	0.17
5	Limed top 4 kg. to 100% b.s., fertilized	0.19	0.19	0.16	0.18
6	Limed bottom 4 kg. to 100% b.s.,fertilized	0.16	0.15	0.16	0.16
7	Limed entire 8 kg. to 150% b.s.,fertilized	0.21	0.20	0.21	0.21
8	Limed top 4 kg. to 150% b.s., fertilized	0.18	0.16	0.18	0.17
9	Limed bottom 4 kg. to 150% b.s.,fertilized	0.15	0.16	0.18	0.16
	Second Cutting (6-12-61)				
1	No lime, no fertilizer	0.20	0.10	0.20	0.17
2	No lime, fertilized	0.20	0.20	0.23	0.21
3	Limed entire 8 kg. to 150% b.s., no fert.	0.25	0.25	0.22	0.24
4	Limed entire 8 kg. to 100% b.s.,fertilized	0.33	0.40	0.25	0.33
5	Limed top 4 kg. to 100% b.s., fertilized	0.31	0.38	0.33	0.34
6	Limed bottom 4 kg. to 100% b.s.,fertilized	0.30	0.26	0.27	0.28
7	Limed entire 8 kg. to 150% b.s.,fertilized	0.35	0.40	0.40	0.38
8	Limed top 4 kg. to 150% b.s.,fertilized	0.39	0.40	0.31	0.37
9	Limed bottom 4 kg. to 150% b.s.,fertilized	0.32	0.33	0.39	0.35

Table 8.--Potassium (K) content of alfalfa forage on Hartsells loam

(Oven-dry basis)

Tmt. No.	Soil Treatment	Replication 1	2	3	Av. of 3 Reps.
		%	%	%	%
	First Cutting (5-16-61)				
1	No lime, no fertilizer	2.35	1.60	1.60	1.85
2	No lime, fertilized	2.25	3.90	3.55	3.23
3	Limed entire 8 kg. to 150% b.s., no fert.	1.60	1.25	1.20	1.35
4	Limed entire 8 kg. to 100% b.s.,fertilized	2.65	2.75	2.50	2.63
5	Limed top 4 kg. to 100% b.s., fertilized	2.80	2.90	2.60	2.77
6	Limed bottom 4 kg. to 100% b.s.,fertilized	3.00	3.15	3.25	3.13
7	Limed entire 8 kg. to 150% b.s.,fertilized	2.70	2.65	2.75	2.70
8	Limed top 4 kg. to 150% b.s., fertilized	2.60	2.80	2.80	2.73
9	Limed bottom 4 kg. to 150% b.s.,fertilized	3.00	2.90	3.00	2.97
	Second Cutting (6-12-61)				
1	No lime, no fertilizer	2.65	2.40	2.30	2.45
2	No lime, fertilized	3.70	3.75	4.15	3.87
3	Limed entire 8 kg. to 150% b.s., no fert.	2.30	2.35	2.05	2.23
4	Limed entire 8 kg. to 100% b.s.,fertilized	3.70	3.80	3.20	3.57
5	Limed top 4 kg. to 100% b.s., fertilized	3.05	2.45	3.20	2.90
6	Limed bottom 4 kg. to 100% b.s.,fertilized	3.95	4.15	4.20	4.10
7	Limed entire 8 kg. to 150% b.s., fertilized	3.25	3.55	4.00	3.60
8	Limed top 4 kg. to 150% b.s., fertilized	3.35	3.35	3.75	3.48
9	Limed bottom 4 kg. to 150% b.s.,fertilized	4.60	4.15	4.15	4.30

Table 9.--Calcium (Ca) content of alfalfa forage on Hartsells loam

(Oven-dry basis)

Tmt. No.	Soil Treatment	Replication 1	Replication 2	Replication 3	Av. of 3 Reps.
		%	%	%	%
	First Cutting (5-16-61)				
1	No lime, no fertilizer	2.35	2.15	2.70	2.40
2	No lime, fertilized	1.85	1.70	2.15	1.90
3	Limed entire 8 kg. to 150% b.s., no fert.	3.45	4.20	4.40	4.02
4	Limed entire 8 kg. to 100% b.s.,fertilized	3.35	3.30	3.60	3.42
5	Limed top 4 kg. to 100% b.s., fertilized	3.30	3.10	3.55	3.32
6	Limed bottom 4 kg. to 100% b.s., fertilized	3.10	3.55	2.95	3.20
7	Limed entire 8 kg. to 150% b.s.,fertilized	2.80	3.15	2.95	2.97
8	Limed top 4 kg. to 150% b.s., fertilized	3.45	3.10	3.35	3.30
9	Limed bottom 4 kg. to 150% b.s.,fertilized	3.55	3.45	3.30	3.43
	Second Cutting (6-12-61)				
1	No lime, no fertilizer	1.90	1.90	2.30	2.03
2	No lime, fertilized	1.40	2.15	1.25	1.60
3	Limed entire 8 kg. to 150% b.s., no fert.	2.35	2.15	2.75	2.42
4	Limed entire 8 kg. to 100% b.s.,fertilized	1.45	1.60	1.90	1.65
5	Limed top 4 kg. to 100% b.s.,fertilized	1.25	1.40	1.25	1.30
6	Limed bottom 4 kg. to 100% b.s.,fertilized	1.40	1.30	1.15	1.28
7	Limed entire 8 kg. to 150% b.s.,fertilized	1.75	1.70	1.70	1.72
8	Limed top 4 kg. to 150% b.s., fertilized	1.90	1.70	1.60	1.73
9	Limed bottom 4 kg. to 150% b.s.,fertilized	1.50	1.50	1.95	1.65

Table 10.--Magnesium (Mg) content of alfalfa forage on Hartsells loam

(Oven-dry basis)

Tmt. No.	Soil Treatment	Replication 1	2	3	Av. of 3 Reps.
		%	%	%	%
	First Cutting (5-16-61)				
1	No lime, no fertilizer	0.75	0.55	0.70	0.67
2	No lime, fertilized	0.40	0.35	0.35	0.37
3	Limed entire 8 kg. to 150% b.s., no fert.	0.60	0.75	0.75	0.70
4	Limed entire 8 kg. to 100% b.s.,fertilized	0.55	0.55	0.60	0.57
5	Limed top 4 kg. to 100% b.s.,fertilized	0.55	0.55	0.55	0.55
6	Limed bottom 4 kg. to 100% b.s.,fertilized	0.55	0.55	0.50	0.53
7	Limed entire to 150% b.s., fertilized	0.50	0.55	0.55	0.53
8	Limed top 4 kg. to 150% b.s., fertilized	0.50	0.50	0.55	0.52
9	Limed bottom 4 kg. to 150% b.s.,fertilized	0.55	0.55	0.60	0.57
	Second Cutting (6-12-61)				
1	No lime, no fertilizer	0.40	0.65	0.95	0.67
2	No lime, fertilized	0.40	0.55	0.35	0.43
3	Limed entire 8 kg. to 150% b.s., no fert.	0.75	0.65	0.65	0.68
4	Limed entire 8 kg. to 100% b.s.,fertilized	0.40	0.45	0.55	0.47
5	Limed top 4 kg. to 100% b.s., fertilized	0.35	0.45	0.35	0.38
6	Limed bottom 4 kg. to 100% b.s.,fertilized	0.40	0.40	0.35	0.38
7	Limed entire 8 kg. to 150% b.s., fertilized	0.40	0.45	0.50	0.45
8	Limed top 4 kg. to 150% b.s.,fertilized	0.55	0.45	0.45	0.48
9	Limed bottom 4 kg. to 150% b.s.,fertilized	0.45	0.40	0.55	0.47

fertilized and in the second cutting for the treatment where the bottom layer of soil was limed to 150 per cent base saturation (4.30 per cent). Differences were found in the potassium content of the forage in the two cuttings. In all the treatments the second cutting contained a higher level of potassium than the first. In both cuttings of the limed-fertilized group of treatments the potassium content was higher where the lime was mixed in the bottom layer of soil.

Calcium. The calcium content of the forage (Table 9) also varied in the two cuttings; however, unlike potassium, calcium was higher in the first cutting. In both cuttings it was highest where the soil was limed but not fertilized --- 4.02 per cent and 2.42 per cent for the first and second cuttings, respectively. As an average of the two cuttings it was lowest (1.75 per cent) where the soil was fertilized but not limed. There was no clear indication of any differences in calcium content of the forage that could be attributed to placement of lime.

Magnesium. The magnesium content (Table 10) varied from 0.37 to 0.70 per cent in the first cutting and from 0.38 to 0.68 per cent in the second cutting. The highest magnesium content in both cuttings was found where the soil was limed to 150 per cent base saturation but not fertilized. There was no indication of any variation in the magnesium content due to placement of lime. Within the limed-fertilized group of treatments the magnesium content of the forage was consistently higher in the first cutting than it was in the second cutting; it was like calcium, but unlike potassium, in this respect.

III. CHEMICAL PROPERTIES OF THE SOIL

The results of the chemical determinations made on the soil at the end of the experiment are presented in Table 11 and 12. Table 11 contains the data on soil reaction (pH), while Table 12 contains the data on the phosphorous and potassium levels of the soil. In both tables the data for the upper and lower layers of soil are shown separately.

Liming and soil reaction.

The pH values of the soils were greatly influenced by the lime treatments. Table 11 gives the pH values of the three replications and of the two layers for each treatment. Treatments limed to 150 per cent base saturation generally showed higher pH values than those limed to 100 per cent base saturation. Differences in pH values for the treatments where the soil was limed either in the top or bottom layer compared to the unlimed layer were rather pronounced and ranged from 1.4 to 2.3 units. The highest pH values were recorded for the treatment where the soil was limed to 150 per cent base saturation but was not fertilized.

Phosphorous and potassium levels of the soil.

Phosphorous and potassium values expressed in pounds per acre are shown in Table 12. Values for the two layers of soil are shown separately.

The potassium and phosphorous levels of the limed soil at the end of the experiment were markedly less than those of the unlimed soil. At both base saturation, lower phosphorous and potassium values were obtained where the soil was limed to full depth than where the soil was limed in only one layer.

Table 11.--Soil reaction (pH values) of Hartsells loam at conclusion of alfalfa lime experiment

Tmt. No.	Soil Treatment	Replication 1	2	3
	Upper 4 kg. of Soil (0 - 4 Inches)			
1	No lime, no fertilizer	5.1	5.0	4.8
2	No lime, fertilized	4.2	5.1	5.0
3	Limed entire 8 kg. to 150% b.s., no fert.	7.3	7.3	7.4
4	Limed entire 8 kg. to 100% b.s., fertilized	6.7	7.2	6.8
5	Limed top 4 kg. to 100% b.s., fertilized	6.9	7.0	6.9
6	Limed bottom 4 kg. to 100% b.s., fertilized	5.3	5.3	5.2
7	Limed entire 8 kg. to 150% b.s., fertilized	7.1	7.2	6.8
8	Limed top 4 kg. to 150% b.s., fertilized	7.2	6.7	7.3
9	Limed bottom 4 kg. to 150% b.s., fertilized	5.2	5.2	5.0
	Lower 4 kg. of Soil (4 - 8 Inches)			
1	No lime, no fertilizer	4.8	4.7	4.7
2	No lime, fertilized	4.5	4.5	4.7
3	Limed entire 8 kg. to 150% b.s., no fert.	7.1	7.2	6.9
4	Limed entire 8 kg. to 100% b.s., fertilized	6.5	6.9	6.7
5	Limed top 4 kg. to 100% b.s., fertilized	4.7	4.8	4.9
6	Limed bottom 4 kg. to 100% b.s., fertilized	6.6	6.6	6.6
7	Limed entire 8 kg. to 150% b.s., fertilized	7.1	6.8	6.9
8	Limed top 4 kg. to 150% b.s., fertilized	4.7	5.5	5.0
9	Limed bottom 4 kg. to 150% b.s., fertilized	6.8	6.9	6.7

Table 12.--Phosphorous and potassium levels* of Hartsells loam at conclusion of alfalfa lime experiment

Tmt. No.	Soil Treatment	Replication (P) 1	2	3	Av. of 3 Reps.	Replication (K) 1	2	3	Av. of 3 Reps.
	Upper 4 kg. of Soil (0 - 4 Inches)								
		P (lb./acre)				K (lb./acre)			
1	No lime, no fertilizer	5	4	4	4	153	150	157	153
2	No lime, fertilized	60	57	46	54	1040	265	290	532
3	Limed entire 8 kg. to 150% b.s., no fert.	2	2	3	2	127	123	196	149
4	Limed entire 8 kg. to 100% b.s.,fertilized	29	30	32	30	226	255	300	260
5	Limed top 4 kg. to 100% b.s., fertilized	31	32	30	31	389	353	286	343
6	Limed bottom 4 kg. to 100% b.s.,fertilized	45	43	45	55	353	353	265	324
7	Limed entire 8 kg. to 150% b.s.,fertilized	23	22	30	25	222	226	282	243
8	Limed top 4 kg. to 150% b.s., fertilized	22	27	27	25	238	196	380	271
9	Limed bottom 4 kg. to 150% b.s.,fertilized	49	62	49	53	317	326	251	298
	Lower 4 kg. of Soil (4 - 8 Inches)								
1	No lime, no fertilizer	3	4	3	3	169	169	166	168
2	No lime, fertilized	55	43	42	47	456	488	464	469
3	Limed entire 8 kg. to 150% b.s., no fert.	1	3	3	2	109	90	105	101
4	Limed entire 8 kg. to 100% b.s.,fertilized	35	30	34	33	290	238	304	277
5	Limed top 4 kg. to 100% b.s.,fertilized	57	57	51	55	389	496	349	411
6	Limed bottom 4 kg. to 100% b.s.,fertilized	29	35	30	31	274	242	255	257
7	Limed entire 8 kg. to 150% b.s.,fertilized	21	27	30	26	230	300	260	263
8	Limed top 4 kg. to 150% b.s.,fertilized	65	45	60	57	349	300	335	328
9	Limed bottom 4 kg. to 150% b.s.,fertilized	29	29	25	28	290	238	260	263

*Extracting solution was 0.05 N H_2SO_4 containing 1% $(NH_4)_2SO_4$; soil-solution ratio 1:4. Phosphorus determined colorimetrically in Beckman Model B spectrophotometer; potassium determined in Perkin-Elmer flame photometer.

CHAPTER V

DISCUSSION

The results of the present investigation give useful information regarding certain fertilizer and liming practices. The beneficial effect of limestone in promoting the growth and yield of alfalfa on acid soils is clearly borne out by the results of the study. The Hartsells soil when fertilized and limed to 150 per cent base saturation to full 8-inch depth produced the highest yield of 12.24 grams, while the treatment where the soil was fertilized but not limed gave a yield of only 0.82 gram. The limed but not fertilized treatment produced an average yield of 6.68 gram. The no-lime, no-fertilizer treatment barely produced a harvestable yield -- an average of only 0.18 gram for the two cuttings. Thus, the effect due to liming alone was pronounced, a finding which is supported by many workers (8, 15, 23). While lime by itself increased the yield some 37 times more than that of the unlimed check, a further increase in yield was obtained by adding fertilizer with the lime. The limed-fertilized treatment produced a yield about double that of the limed-unfertilized treatment. As a group, forage yields at 150 per cent base saturation were slightly more than they were at 100 per cent base saturation, although there was no significant difference between them. A failure of the higher rates of lime to result in a significantly higher yields, is in agreement with the findings of Moschler _et al_. (23).

The yield data show the benefical effect of lime on the efficient use of fertilizers and indicate that both lime and fertilizer are important in the production of alfalfa on acid, infertile soils. The favorable effect of lime in the production of alfalfa may be attributed to its influence in correcting aluminum and manganese toxicity, although, this aspect was not investigated in the present study. A higher soil reaction may also have exerted a direct influence on the availability of applied nutrients.

Where no lime was applied the reaction of the soil at the conclusion of the experiment was about the same as it was before it was started, i.e., approximately pH 4.8 (treatments 1 and 2). However, in these two unlimed treatments the pH was as low as 4.2 and as high as 5.1.

Where lime was mixed with the soil at a rate calculated to attain a base saturation of 100 per cent (treatment 4, upper 4 kg. of treatment 5, and lower 4 kg. of treatment 6) the pH was raised to a value of 6.8, or 2 pH units above that of the unlimed soil. Where lime was added at a rate calculated to attain a base saturation of 150 per cent (treatments 3 and 7, upper 4 kg. of treatment 8, and lower 4 kg. of treatment 9), an average value of pH 7.0 was attained, or only 0.2 pH unit higher than that attained with the 100 per cent-base-saturation rate. Where lime was withheld from either the upper or the lower half of the soil column the pH values were not greatly different from those where no lime was added at all. (See upper layer in treatments 6 and 9 and lower layer in treatments 5 and 8). These results would indicate very little movement of lime in the course of this experiment.

MacLean and Cook (17) have reported that the optimum soil reaction for alfalfa when phosphates also were applied, was in most instances pH 6.5 to 7.0.

The present study also revealed that the zone of placement of lime in the soil had a pronounced effect on crop response. Since lime moved very little in the soil profile, the broadcasting of lime on the surface soil without thorough incorporation would be unsatisfactory. This is especially true since the efficient utilization of applied fertilizers depends to a large extent on the lime distribution in an acid soil. In this experiment the highest yields were obtained where the lime was mixed to full soil depth; the second highest yields were obtained where the lime was mixed in the upper 4 inches of soil. Yields were significantly lower where the lime was mixed in the lower 4 inches of soil.

Longenecker and Merkle (16) studied the influence of placement of lime on crimson clover in pots treated with lime in different soil layers. They reported that liming the top 6 inches gave the highest yields. However, they did not find any marked difference in yield when only the top 3-inch was limed. Pohlman (28) reported that maximum yields were obtained where both 0-8 and 8-16 inch layers were limed approximately to neutrality. Experiments conducted in the Midwest which were reviewed and summarized by Jamison _et al._(13) showed that the benefits from deep tillage accompanied by liming and fertilization on corn, oats, sweet clover, and alfalfa were doubtful. The results of the present investigation support Jamison's findings, in so far as that placement of lime in the lower layer of soil did not produce as much forage as was obtained where lime was mixed throughout the soil or in the upper layer.

The results obtained in this study did not throw any additional light on the exact manner in which lime functions in acid soils, but the evidence tends to favor the existing theories. According to Peech and Bradfield (25) the yield responses of crops to application of lime on acid soils are complex and involve many contributing factors, such as calcium deficiency and the toxicity of hydrogen ions, aluminum, iron, and manganese, the relative importance of which vary with different crops and soils. These authors also hold to the view that the poor growth of plants in acid soils is not to be attributed entirely to calcium deficiency, brought about by a low exchangeable calcium content or a low degree of calcium saturation. The results of this experiment support this view. It showed that the level of calcium in the plant was fairly independent of the total supply in the soil and that the plant grown on unlimed soils contained a level of calcium comparable to that of the plant grown on limed soil. Toxicity of certain cations such as aluminum and manganese could partially account for the poor growth of alfalfa on this acid soil (18). Schmehl _et al._ (31) found that toxic quantities of manganese and aluminum greatly inhibited the growth of alfalfa in an acid soil until it was adequately limed. Longenecker and Merkle (16) considered manganese toxicity as a primary cause for the poor growth of plants in many acid soils. They were of the view that quantities of exchangeable manganese and of manganese in displaced soil solutions may be large for soils with low pH. The poor yields on unlimed soils may therefore be due in part to the toxic concentrations of these cations which largely account for the low fertility of acid soils. Liming tends to reduce the concentration of these cations and thereby to facilitate growth of plants.

The utilization by plants of nutrients present in the subsurface horizons is influenced by the physical characteristics of these horizons not only because of their direct effect on root penetration but also because of aeration that might influence nutrient absorption. It has been established, however, that the roots of many crop plants penetrate to considerable depths in many soils. This investigation has shown that the chemical properties of the subsurface soil may materially influence root development where physical conditions are favorable to such penetration.

The difference in root yields of limed and unlimed soils was highly significant. As was the case in forage yields the lowest yields of roots were obtained where lime and/or fertilizer were withheld. The highest yield of roots was obtained in the treatment where the bottom layer of soil was limed to 100 per cent base saturation. The relative percentage of roots in the two soil layers is of particular interest in indicating the effects of liming the different layers. For example, a study of the data in Table 5 reveals that the total root weight was slightly greater where lime was mixed with the soil in the lower half of the pot than it was where it was mixed throughout the entire soil mass or in the upper half of the pot. Moreover, a slightly smaller percentage of the total root weight was found in the top layer of this treatment. As an average of the two rates of liming 69.6 per cent of the total root weight was found in the upper layer of soil where the bottom layer was limed as compared to 73.4 per cent in the upper layer of soil where the upper layer was limed. Also a greater development of small fibrous roots appeared to be associated with the limed zones. Even in the pots where the bottom layer only was limed, large tap roots were noted in the layer above, which upon reaching the bottom layer produced many feeding roots. As an average a greater weight of roots was found where the soil was limed to 100 per cent base saturation than was found where it was limed to 150 per cent base saturation. However, differences between root weights for the two rates of liming and for the three lime placements were not significant.

Since the growth of a plant above ground is so intimately related to its root system, some knowledge of the plant's root system is of value in helping to explain differences in above ground growth. One plant characteristic frequently investigated and reported in the literature is its shoot-root ratio i.e., the proportionate amounts by weight of shoot and root. In the present discussion shoot growth (forage) refers to the total weight of both cuttings of alfalfa, while root growth refers to the total weight of roots extracted from the soil after the second cutting of alfalfa was made.

As an average of all treatments the shoot-root ratio was 1.16, but it was much lower where the soil was unlimed and unfertilized. With this treatment the shoot-root ratio was 0.27 and where fertilized but not limed it was 0.72. The highest shoot-root ratio (1.64) was obtained where the soil was limed throughout but not fertilized. Among the limed-fertilized treatments the lowest shoot-root ratio occurred where the lime was incorporated in the bottom layer only -- an average shoot-rate ratio of 0.89.

That calcium does not move freely in the soil has been very well illustrated in the present investigation. The differences in pH values between limed and unlimed layers determined at the conclusion of the present experiment were very pronounced. There was little neutralization of the acidity in soil layers below or above the zone of lime placement. This indicated that the movement of calcium even 5 months after liming was practically nil. This is in general agreement with the conclusions drawn by Blume (5) who subjected a limed fine sandy loam to severe leaching. Longenecker and Merkle (16) analyzed the soil in pots at the close of the growth period of crimson clover where different layers were limed differently. They also showed a sharp contrast between the limed and unlimed zones in pH value, available phosphate, calcium, magnesium, aluminum and manganese. This suggests very little diffusion of nutrient and toxic ions from one zone to another. The finding of this investigation was, however, in contradiction to the results of Pohlman (28). He observed that there was a definite movement of calcium from both light and heavy lime applications into unlimed layers beneath. He also found that the larger the amount of lime added to the surface 0-8 inches, the greater was the downward movement into the 8-16 inch layer. He, however, contended that the downward movement of lime was probably greater in his experiment than would be expected in the field, since the surface of the soil in which the plants grew was slightly below the rim of the tile, which held most of the water falling on the soil.

When soils are limed, the availability of ions such as potassium and phosphate are generally affected, though there is little agreement as to the magnitude or even the direction of the effect, which usually is not large in any case. Generally, the availability of soil phosphate appears to increase as soils are limed to near neutrality. This may be due to soil or plant factors or both.

Truog (40) is of the opinion that liming the soil up to a pH of 6.6 to 7.0 increases the availability to plants of both the soil phosphorus and applied phosphorus. In the present investigation the phosphorous content of alfalfa forage, particularly the second cutting, supports this view.

Stubblefield and DeTurk (37) have pointed out that phosphorus is converted into living tissues and becomes a part of the organic body, and since the absorption of increasing amounts of phosphorus is accompanied by a corresponding increase in growth, the percentage of phosphorus in the plant tissues generally tends to be a constant. This was not the case in the present study, since the phosphorous content of the plants was found in general to increase with the base saturation level. This was true particularly of the second cutting. The simultaneous increase in growth, yield, and phosphorous content of the plants only suggests the beneficial effect of lime and its distribution in the soil.

As an average of all treatments there was little difference in the P and K levels of the two soil layers. However, attention is called to the fact that the P level in the upper soil layer of treatments 6 and 9 and in the lower soil layer of treatments 5 and 8 was considerably higher than it was in the other limed and fertilized treatments. (See Table 12.) The most likely reason for this is that these layers received no lime; therefore, the strength of the acid extracting solution was not weakened by the liming material. That the limed soil reduced the amount of P extracted is evidenced by the fact that, of the limed and fertilized treatments (treatments 4-9), the average P value was 29 pounds per acre where lime was added to either or both layers as compared to 52 pounds where lime was withheld.

Nitrogen fixation by legumes is markedly influenced by soil reaction. Mehlich and Colwell (20) found that the nitrogen content of soybeans increased regularly with calcium saturation of two mineral soils. In this investigation it was noted that at the higher lime rate, the color of alfalfa was dark green as contrasted with a lighter, yellowish green in the unlimed pots. Moschler _et al_. (23) also reported that the color of alfalfa at the higher lime rates was a darker green than it was at the lower rates. This was presumed to be related to the nitrogen nutrition of the plants. Improved color of alfalfa indicated that a better metabolism of nitrogen was obtained in the limed soil.

The calcium and potassium contents of the alfalfa forage are of particular interest. (See Tables 10 and 11.) In the first cutting the percentage of calcium exceeded that of potassium on the limed-fertilized treatments; the Ca-K ratio was 1.16 to 1. This situation was reversed, however, in the second cutting. In this cutting the percentage of calcium was less than one-half that of potassium; the Ca-K ratio was 0.43 to 1. Where the soil was limed but not fertilized the concentration of calcium was much higher than it was with any other treatment; Ca-K ratios were 2.98 and 1.09 to 1 respectively in the first and second cuttings. This agrees with the general concept that calcium and potassium are negatively correlated. In most cases high levels of potassium have been found to be associated with lower levels of calcium and magnesium in plants.

It might be expected that an increase in calcium content of alfalfa forage would be accompanied by a decrease in magnesium content. This was not true in this study as can be seen in Table 12. In general, as the calcium content increased the magnesium content also increased. It is presumed that this occurred because a dolomitic limestone was used.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A greenhouse experiment was conducted to determine the effect of lime and fertilizer and zone of lime incorporation on forage yield, root development, and nutrient uptake of alfalfa. The soil was Hartsells loam of low nutrient status and acid in reaction. The crop grew in 8 kilograms of soil placed in 2-gallon glazed pots. The experiment covered the period January 19 to June 12, 1961, during which time two cuttings were made. Some of the findings were as follows:

1. Significant growth and yield response to the application of lime was obtained. The lowest yield of alfalfa forage was obtained on the no-lime, no-fertilizer treatment. Highest yields were recorded in treatments where the soil was limed to full depth to 100 and 150 per cent base saturation.
2. Placement of lime played a significant part in the growth, yield, and root development of the crop. Forage yields were decidedly inferior where only the bottom layer of soil (4- to 8-inch depth) was limed than where the soil was limed to full depth or in the upper layer.
3. Like the top growth, the lowest yield of roots was obtained in the unlimed and unfertilized treatment, and the highest where the bottom layer of soil was limed to full depth at 100 per cent base saturation. While there were

significant differences in yield between the limed and unlimed treatments, there was no significant difference in the yields among the limed-fertilized treatments either for rate of liming or for placement of lime.

4. The P content of the forage ranged from a low of 0.11 per cent to a high of 0.38 per cent; on the average it was higher on the fertilized soil limed to 150 per cent base saturation than it was where limed to 100 per cent base saturation. It was generally higher in the second cutting than in the first.

5. The K content of the forage ranged from 1.35 per cent to 4.30 per cent. In both cuttings it was lowest where the soil was limed to 150 per cent base saturation, but not fertilized. In the limed-fertilized group of treatments the K content of the forage was highest where the lime was mixed in the bottom layer of soil.

6. The Ca content of the forage also varied in the two cuttings; however, unlike K, Ca was higher in the first cutting. In both cuttings it was highest where the soil was limed but not fertilized -- 4.02 per cent and 2.42 per cent for the first and second cuttings, respectively. As an average of the two cuttings it was lowest (1.75 per cent) where the soil was fertilized but not limed.

7. The Mg content of the forage varied from 0.37 per cent to 0.70 per cent; it, like Ca, was higher in the first cutting.

8. The P and K levels of the limed-fertilized soil, as indicated by soil test, were markedly less than those of the unlimed-fertilized soil. This apparently was due to a reduction in the strength of the acid extracting solution brought about by the addition of lime.

9. The liming of this acid soil (pH 4.7-4.8) to a calculated 100 per cent base saturation had raised the pH at the end of the experiment to a value of about 6.8, while liming to 150 per cent base saturation had raised it to about pH 7.0. Little or no change from the original pH of the unlimed layers indicated very little movement of lime.

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