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To the Graduate Council:

I am submitting herewith a thesis written by Laxminarayan Annappa Dixit, entitled "The Influence of Soil Properties and Lime Upon Nutrient Content and Yield of Alfalfa and Lespedeza." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirement for the degree of Master of Science, with a major in Agronomy.

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THE INFLUENCE OF SOIL PROPERTIES AND LIME UPON NUTRIENT CONTENT AND YIELD OF ALFALFA AND LESPEDEZA

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Laxminarayan Annappa Dixit

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CHAPTER I

INTRODUCTION

Application of lime to acid soils as a part of soil management has probably been practiced for 3000 years at least. Edmund Ruffin, a practical farmer from Virginia, was perhaps the pioneer in the application of lime in this country.

In the humid regions of the advanced countries in the world, liming has been accepted today as one of the essential practices in the profitable farming and efficient soil management. A large amount of work has been conducted on this topic, many data have been accumulated and countless numbers of articles, research papers and other publications have been written on this vitally important subject.

Considerable progress has also been made in the techniques used for estimating the lime requirement for various soils. The most primitive methods like the use of litmus paper and other similar tests have given place to the modern procedures like the use of pH meters, buffer solutions and other refined techniques which are more precise and at the same time are sufficiently rapid for use on mass scale. The concept of the cause of soil acidity has undergone modification during the past few years and the significance of exchangeable aluminum as a major cause of acidity has been brought to the forefront.

In spite of the fact that soil acidity is a problem of agriculture and not withstanding the large magnitude of research carried out on the subject, it is so complex that the exact nature of the whole

situation is still not understood. Considerable amount of research is needed before predictions can be made precisely and with considerable rapidity as to the exact requirement of lime for a particular crop under a specified set of soil and management conditions.

This study was undertaken with the following objectives in mind:

1. To characterize selected soils and evaluate the influence of certain soil properties on the lime requirement of these soils.

2. To determine the effects of the rate of lime application on the yield and composition of alfalfa and lespedeza on the selected soils.

CHAPTER II

REVIEW OF LITERATURE

I. RESPONSE OF CROPS TO LIME

Numerous field and greenhouse experiments have been conducted with a number of crops to study the effect of lime on soils having different characteristics.

Singh and Seatz (35) working with Hartsells loam which was very low in phosphorus and had a pH of 4.7 found that the highest yield of alfalfa was obtained when lime and phosphorus were applied to the soil at the highest rates of 4 tons of lime and 120 pounds of P per acre. Little or no alfalfa was produced, at all rates of P without the application of lime. The percentages of Ca, Mg and P in the forage increased with phosphorus and lime but the K content decreased.

Chin et al. (7) conducting experiments on several soils in Minnesota observed that the yields of alfalfa were directly proportional to the rate of lime applied up to 100 tons per acre with one exception. They attributed this response of alfalfa to its high requirement for calcium.

Similar results have been reported by other workers on lespedeza. Albrecht and Klemme (1) conducted field experiments at Missouri Agricultural Experiment Station by applying superphosphate with and without lime to Korean lespedeza. They found that superphosphate with limestone increased the yield 80% over the control.

Moser (28) in a greenhouse experiment adjusted the pH of Cecil sandy loam to different levels with $Ca(OH)_2$ and H_2SO_4. He found that lespedeza produced highest yield on this soil at a pH range of 5.0 to 5.5 and the yield decreased when the pH range of the soil was raised to 7.0 to 7.5. The results of another experiment by Moser (27) showed that Ca supplied at low pH was a more important factor than pH. Lespedeza produced maximum yield at pH 5.2 and needed more Ca than soybean and sorghum.

Mehlich and Colewell (25) treated three mineral soils having differences in the types of clay and in the pH-base saturation relationships with $Ca(OH)_2$ to various degrees of Ca saturation. The results showed that on the soil dominated by 2:1 clay yields of cotton and soybeans increased with each increment of calcium even up to 80% saturation, the highest level tried in the experiment. In the case of soil having 1:1 clay, however, the yields increased up to the base saturation level of only 40%. A similar result was obtained by Dawson (10) on four pedologically different soils. He observed that on Brown Latosol the optimum growth of alfalfa was obtained at 40% base saturation whereas on other soils the base saturations was 80 to 100% when optimum yields were obtained. It was also noticed that the soil pH varied considerably on different soils at the same base saturation. He pointed out that the nature of clay, the presence of organic matter and exchangeable Al and Mn contents might be responsible for the varied behavior of these soils.

Coleman et al. (8) suggested that the base saturation of the permanent charge on the clay fraction is important and there is no

significant benefit from liming the soils to higher levels once the exchange sites were occupied by bases. Moschler et al. (26) conducting a field experiment on Tatum silt loam applied dolomitic and calcitic limestones at rates varying from 0 to 16 tons per acre. The yield of alfalfa increased throughout the entire range of lime rate but was not significant beyond 1-ton rate of lime. The pH at this rate was only 5.7. They further observed that the yields of alfalfa at the various lime levels agreed with the percentage base saturation calculated from the permanent charge and not with the base saturation based on cation exchange capacity.

II. TOXICITY OF ALUMINUM TO PLANTS

Numerous investigators working with many plants have found that aluminum in the growing medium has toxic effects on the growth of plants.

Hartwell and Pember (14) during the second decade of the present century grew rye and barley in water and sand culture as well as in soil extracts with the addition of different chemicals and pointed out that the toxic effect observed on these crops was attributable largely to the presence of aluminum. Conner and Sears (9) conducted experiments by growing several cereal crops in a series of water cultures with aluminum salts and their corresponding acids. They concluded that the toxicity of aluminum salts was due to the aluminum ions more than it was due to hydrogen ions to such crops as barley and that if phosphate was used in the nutrient solution the toxicity of aluminum was reduced.

In the early 1920's Blair and Prince (5) leached a number of soils with distilled water and analyzed the extract for soluble Fe, Al and

other constituents. They also grew plants in the soil extracts and observed that something in the extracts from acid soils was responsible for poor development of roots of plants. They inferred from the result of the experiment that the soluble Al compounds constitute one of the causes of toxicity in soils.

To gain additional information on the quantities of Al present in the soil solutions extracted from soils of different reactions and also to study the effect of Al on the growth of plants in relation to reaction, Magistad (21) conducted an elaborate greenhouse study with a variety of crops like barley, rye, alfalfa, red clover, corn, oats and soybeans. These crops were grown in two series of quartz sand cultures at various reactions, supplied with a nutrient solution which was saturated with Al in one of the series. In addition, he also determined the solubility of Al compounds in water, nutrient solutions and soil extracts at various reactions. On the basis of the results of the greenhouse experiment he postulated that for all crops studied, the benefit of liming soil appeared to come almost equally from a decrease in acidity and soluble Al when the soil has a pH of 5.0 or lower. He observed the quantity of Al_2O_3 to be 1 to 2 ppm. at pH value of 5.0.

McLean and Gilbert (24) grew several crops including alfalfa in solution culture to study the susceptibility of these crops to the toxicity of Al and to evaluate the effect of phosphate in preventing Al injury. They found that a very low concentration of Al (3 to 13 ppm.) was stimulating plant growth whereas higher concentrations were toxic. Aluminum when present in the medium even in non-diffusable

colloidal form was observed to induce toxicity if it be in contact with barley roots. Phosphate when added to the solution with the aluminum compounds, completely overcame the toxic effect of Al on plant growth presumably because of the precipitation of Al as aluminum phosphate.

Gilbert and Pember (12) observed that lettuce grown in a pH range of 3.2 to 7.5 in solution cultures did not show any appreciable deviation in the yields obtained. But when aluminum sulphate was added to the solution the yield was considerably depressed. Likewise, the yields of barley grown on acid soil samples of several types obtained from widely separated areas showed a close correlation with the "active" Al content of the soils rather than with their pH. They, therefore, concluded that the Al content rather than acidity has a great inhibiting effect on the growth of lettuce and barley.

Arnon and Johnson (2) conducting experiments under controlled conditions with nutrient solutions and sand culture, discovered that many plant species produce normal growth with pH values as low as those encountered in most acid soils. They pointed out that the H ion per se is not to be considered as the cause for poor growth of many plants on acid soils.

Wright and Donahue (43) used radioisotope P^{32} to study the accumulation of P in barley. The radioautograph revealed a large accumulation of P^{32} in root and very little in tops of plants grown in contact with Al. Root sections of barley grown in solution containing Al when stained by Heidenhain's iron hematoxylin process showed Al accumulation on root surfaces and throughout the corticle region. Very little Al was

present in the vascular system. There was also considerable modification in the internal structure of plant roots. It was inferred from the results of the experiment that Al does inactivate phosphorus primarily within the roots of the plants and this interferes with the normal phosphorus metabolism of the plant and adversely affects the yield obtained.

Ligon and Pierre (18) conducting experiments with corn, sorghum and barley in nutrient solutions found that 1 ppm. of Al in the solution considerably reduced the yield of all these crops and slightly more than 2 ppm. of Al reduced the yield of barley to an extremely low level.

More recently Vlamis (42) displaced solutions from both limed and unlimed soils and grew barley in the extracts. He found that the solution from unlimed soil was toxic due to the presence of Al in the extract and was responsible for the poor growth of the crop.

III. METHODS OF EXTRACTING Al FROM SOIL AND DETERMINATION OF Al

Numerous solutions have been tried for extracting Al from soils and clays. McLean *et al.* (23) selected 1 N NH_4OAc at pH 4.8 due to its superiority over either $Ba(OAc)_2$ or $BaCl_2$ for extraction of Al from Ohio soils representing a wide range of extractable Al.

Pratt and Bair (33) studied a number of acid soils to determine which of the three solutions might best extract exchangeable Al from the soil. As compared to normal unbuffered solutions of $BaCl_2$ or KCl the NH_4OAc solution at pH 4.8 extracted less Al from soils of low pH and more Al from soils of high pH. They found that the pH of the soil

was always brought to 4.8 by extracting with NH_4OAc of pH 4.8 which resulted in the increase in pH of highly acid soils and a decrease in pH for less acid soils. It was also observed that aluminum hydroxide prepared fresh was found to have relatively high solubility in NH_4OAc of pH 4.8 compared to that in KCl. They also found that extracting soil with N KCl and allowing a minimum time of contact of the first portion of the extract with the soil probably gave a more reliable estimate of exchangeable Al than was obtained with NH_4OAc at pH 4.8.

Yuan and Fiskell (46) used N NH_4OAc buffered at six different pH values for extracting Al from soils and found that the lower the pH of the solution the more Al was extracted. They also observed that more Al was extracted by neutral normal solutions of $BaCl_2$, $CaCl_2$, KCl, NH_4Cl and $BaCl_2$ in triethanolamine buffered to pH 8.1 than by neutral normal NH_4OAc. Among the neutral salts, divalent cations appeared to be more efficient. Much more Al was extracted by $BaCl_2$ in triethanolamine than any of the other neutral salts and this fact they attributed to the complexing capacity of triethanolamine.

Lin and Coleman (19) observed that when 1 N. salt extractants were used for leaching Al saturated soils, the Al^{+++} displaced was very close to the exchange capacity of these soils. In the case of acid subsoil the Al extracted was nearly equal to the exchange capacity less the total of exchangeable Ca and Mg. Prolonged leaching with neutral salt solutions did not significantly increase the Al extracted over that present in the exchange sites. The salt solutions when acidified, however, continued to dissolve Al from the soil. So long as the leaching was

sufficiently exhaustive 1 N. solutions of KCl, $CaCl_2$ and NaCl were equally effective in extracting Al from a number of soils and clays. For limited leaching they found KCl to be the most effective and NaCl the least.

Numerous methods are available for the determination of Al from plant material and soil extracts. The aluminon method standardized by Smith et al. (36) and modified by Yuan and Fiskell (45) and Page and Bingham (30), the use of Eriochrome cyanine R. as suggested by Jones and Thurman (17) are some of the common methods used.

Yuan (44) described a simple titration method for the determination of exchangeable Al and H and total extractable acidity by making use of the formation of stable, complex compound by Al with NaF. Soil is extracted with N KCl and the leachate is titrated with standard NaOH using phenolpthelein as indicator which gives the measure of total extractable acidity. The NaF is then added to the solution which forms a stable, sodium fluoaluminate, liberating equivalent quantity of NaOH. Titration is made with standard HCl which gives an estimate of Al in the extract.

IV. CALCIUM-MAGNESIUM RATIOS IN SOILS AND PLANTS

Loew was probably the first man to propose the hypothesis of Ca:Mg ratio. In the first part of the bulletin written by Loew and May (20) Loew has quoted many examples showing that the calcium-magnesium ratios vary widely from soil to soil and also from one plant species to other. For example, the ratio of lime to magnesia varied from 1:0.12 in alfalfa to 1:1.02 in sugar beet. In the second part of the bulletin reported by May are given the details of experiments which were set up

as water, sand and soil culture to study the effects of various amounts of calcium and magnesium salts on the growth of some of the economic plants. The results showed, in general, an adverse effect on the growth of plants by an excess of magnesia in the growth medium; whereas the application of excess lime produced symptoms of magnesium deficiency in plants.

Halstead et al. (13) conducting a greenhouse experiment with the surface soils treated with various amounts of $CaCO_3$ and $MgCO_3$ found that the Ca:Mg ratio of alfalfa reflected the Ca:Mg ratio established in the soil by the addition of calcium and magnesium carbonates. The low Ca:Mg ratio of 0.6 in alfalfa grown with applied phosphorus and an excess of $MgCO_3$ in Mountain sandy loam was associated with low exchangeable and water soluble Ca:Mg ratios in the soil and also with a reduction in alfalfa yield from that obtained with a corresponding excess of $CaCO_3$.

Hunter (15) treated soil to different Ca:Mg ratios ranging from 1/4 to 32/1 and found that the yield of alfalfa and weight of roots were not significantly affected by variations of Ca:Mg ratios in the soil. He, however, found that the magnesium was absorbed to a much less extent and decreased rapidly as the amount of magnesium decreased with increasing Ca:Mg ratio in the soil.

Chapman and Gray (6) working with the nutrition of oil palm found that magnesium deficiency was highly correlated with the absolute amount of magnesium in the leaves and also with the CaO/MgO ratio. It was thus hard to infer whether the ratio was of importance to the nutrition of the oil palm. Moser (29) conducted a study with various crops and found

no correlation between the replaceable Ca:Mg ratio and the crop yield. He suggested that the determining factor for crop production was probably the amount of calcium.

Jacob (16) in his comprehensive book on magnesium has reconciled the contradictory results obtained by the various research workers by stating that the calcium to magnesium ratio is only a special case and in addition there are also antagonisms to other cations. He thus points out that it is not only necessary to provide optimal calcium to magnesium ratio but it is also important to maintain the correct harmonious proportions between all the cations.

CHAPTER III

MATERIALS AND METHODS

Four soil types of importance in Tennessee and adjoining states were selected. These soils have been formed from four types of parent materials common in this state. Grenada silt loam is derived from loess, Dewey silty clay loam from dolomitic limestone, Sequoia silt loam from shale and Hartsells sandy loam from sandstone.

Bulk samples were collected from the Ap horizons of each of the soils. The samples were air dried, passed through a shredder and stored. Representative samples were passed through a 2 mm. sieve for analytical use in the laboratory.

I. GREENHOUSE EXPERIMENTS

Alfalfa (Medicago sativa, variety--Buffalo) and Korean lespedeza (Lespedeza stipulacea) were grown in each of the four soils at four lime levels, viz., 1, 2, 4 and 6 tons per acre (2, 4, 6 and 12 me. of Ca per 100 g. of soil). Finely divided, pure calcium carbonate was used as the liming material. An application of 88 pounds of P (200 pounds of P_2O_5) as monocalcium phosphate, 164 pounds of K (200 pounds of K_2O) as potassium chloride, 15 pounds of nitrogen in the form of ammonium sulfate and of 3.1 pounds of boron as sodium borate per acre was made to each of the treatments.

For the alfalfa experiment, to 12.8 kg. of each soil the required quantities of lime and fertilizers were added and mixed thoroughly in a

soil blender. The mixture was divided equally into four parts and each 3.2 kg. portion of the mixture was placed in number 10, plastic lined tin cans. Three replications were used in the alfalfa experiment. The soil in the fourth set of cans was used for studying periodic changes in the pH.

The cans were watered with demineralized water to 20% by weight of soil on May 23, 1962, and approximately 25 alfalfa seeds were planted on May 27, 1962. Rhizobia culture was added and mixed with the soil before seeding.

After germination and establishment the number of plants was reduced to 15 per can. Watering was done periodically with demineralized water and the soil moisture content was maintained at 20% by weight.

During the course of their growth the plants tended to lodge and were supported by wooden sticks and string. One spraying was done for control of the leaf miner during the first growth. Plants were sprayed during each of the second and third growths for control of aphis.

The first crop was harvested on August 16, eighty days after planting, a second cutting was taken on September 8, twenty-four days after the first harvest, and a third on October 16, thirty-eight days after the second cutting. The plants were cut about 2 inches above the soil surface. The forage from each can was dried in an oven at 70°C. and weighed. The first and third crops were ground in a small Wiley mill and stored in bottles for laboratory analysis.

Soon after the third harvest, the above ground portions of plant residue were clipped off and the soil from each can was washed away with

a jet of water. The organic matter and other foreign materials were separated out by floating the alfalfa roots in an enameled dish containing water. The cleaned roots were dried in an oven at 70°C. and weighed.

Soil samples were collected periodically from the cans where no alfalfa was planted. The first sampling was made fifteen days after the first watering and two more samples were taken at intervals of fifteen days.

Another set of 64 cans (4 soils, 4 lime rates and 4 replications) was prepared following the same procedure as outlined above for alfalfa and about 20 seeds of Korean lespedeza per can were planted on July 21, 1962. After germination and establishment the plants were thinned to 10 per can. Periodical watering with demineralized water was done to maintain the moisture level at 20% by weight of soil. The crop was harvested on September 30, 1962, seventy-two days after planting. The plant material was dried, weighed, milled and stored for analysis.

II. LABORATORY STUDY

Plant Material

The plant materials of first and third cuttings of alfalfa and the one harvest of lespedeza were analyzed for calcium, magnesium, potassium and phosphorus.

Portions weighing 0.2 g. were digested with 2 ml. of concentrated HNO_3 and 3 ml. of perchloric acid and an aliquot was used for the determination of phosphorus as per the modified procedure suggested by Sterges, Hardin and MacIntire (37). A second aliquot was utilized for the

determination of calcium, magnesium and potassium with the Beckman flame photometer after precipitating SO_4 and PO_4 from the extract.

Soil

Untreated soil samples were analyzed to determine some of the important physical and chemical properties. Likewise, pH and aluminum content were determined for the soil samples which were collected periodically from the set of cans kept in the greenhouse without growing alfalfa.

The Beckman pH meter was used for determining the pH of the soils. pH was determined in water, using a 1:1 soil-water ratio and also in 0.01 M $CaCl_2$. In addition, the soil samples were leached with water to remove the soluble salts and the pH was determined using 1:1 soil-water ratio.

Mechanical analysis was made by the International pipette method. Organic matter was estimated by the chromic acid oxidation procedure.

For determining the cation exchange capacity and the exchangeable bases, 10 g. samples were leached with 1 N. neutral ammonium acetate to about 250 ml. The Ca, Mg and K were determined by a Beckman flame photometer from the leachate after precipitating the SO_4 and PO_4. The soils on the funnels were washed thoroughly with ethyl alcohol and were distilled to expell the adsorbed ammonia. The cation exchange capacity was calculated from the ammonia in the distillate.

Exchangeable H and Al of the samples were determined by titration as outlined by Yuan (44).

CHAPTER IV

RESULTS

I. PROPERTIES OF UNTREATED SOILS

The results of physical and chemical analyses of the soils are presented in tables 1 through 3. Results in these tables show that there is a wide variation in the different properties among the four soils studied in this investigation. The main features of these soils are pointed out in the following paragraphs.

Highest amount of clay, or about 29%, was found in Dewey and the lowest, or about 11%, in Hartsells. Grenada and Sequoia with a little more than 21% of clay were intermediate in this respect between Dewey and Hartsells.

Hartsells had high content of 2.6% of organic matter and was followed by Dewey and Sequoia which contained about 2% of organic matter. Grenada, however, had very low organic matter content of only 0.7%.

Dewey and Sequoia contained about 5 me. of exchangeable Ca per 100 g. of soil. The exchangeable Ca contents of Grenada and Hartsells were about one half as large. In the case of exchangeable Mg Grenada had the highest amount of 2.2 me. per 100 g. which nearly equalled exchangeable calcium found in this soil. Hartsells on the other hand had a very low level of exchangeable Mg and a very high exchangeable Ca:Mg ratio. Dewey and Sequoia were intermediate between Grenada and Hartsells

Table 1.--Particle size distribution and organic matter content of samples of surface soil from four series.

Soil Series	Particle size distribution, percent			Organic matter
	Sand	Silt	Clay	
	>0.05 mm.	0.05-0.002 mm.	<0.002 mm.	percent
Dewey	17.8	53.3	28.9	2.1
Grenada	12.3	65.8	21.9	0.7
Hartsells	56.9	31.7	11.4	2.6
Sequoia	27.0	51.5	21.5	2.0

Table 2.--Exchangeable bases and exchange acidity of untreated soil samples from the surface horizons of four soil series.

Soil Series	Exchangeable bases* me./100 g.				Exchange acidity** me./100 g.		
	Ca	Mg	K	Total	Al	H	Total
Dewey	5.3	1.0	0.2	6.5	0.1	0.0	0.1
Grenada	2.6	2.2	0.2	5.0	2.6	0.2	2.8
Hartsells	2.7	0.2	0.2	3.1	0.5	0.0	0.5
Sequoia	5.4	1.5	0.4	7.3	0.2	0.0	0.2

*NH_4OAc extracted.

**KCl extracted.

Table 3.--Cation exchange capacity and base saturation of untreated soil samples from the surface horizons of four soil series.

Soil Series	Cation exchange capacity, me./100 g.		Base saturation, %	
	NH_4OAc, pH 7	Permanent charge*	pH 7	Permanent charge
Dewey	11.1	6.6	58.2	98.8
Grenada	11.3	7.6	44.1	66.1
Hartsells	6.3	3.6	49.1	85.9
Sequoia	12.3	7.5	59.0	98.0

*Total me. of bases plus me. of Al extracted with N KCl.

with respect to exchangeable Mg and contained 1.0 and 1.5 me., respectively.

Grenada contained the highest exchange acidity of 2.8 me. per 100 g. whereas Dewey had a very low content. Hartsells and Sequoia contained moderate and low exchange acidity of 0.5 and 0.2 me. per 100 g., respectively. Most of the exchange acidity (KCl extracted) was made up of exchangeable aluminum in all these soils.

The cation exchange capacities determined by neutral N NH_4OAc method were about the same for Dewey, Grenada and Sequoia and varied from 11.1 to 12.3 me. per 100 g. of soil. Hartsells, however, had a low cation exchange capacity and the value was about one half that of the other three soils. A similar trend was observed in the quantity of permanent charge in these soils. The values were about the same for Dewey, Grenada and Sequoia. Hartsells was lower.

Base saturations calculated on the basis of cation exchange capacity at pH 7.0 were about the same for Dewey and Sequoia and the values were higher than those of the other two soils. Further, the permanent exchange sites in Dewey and Sequoia were nearly saturated with bases. In the case of Grenada, the percent base saturation was very low and only about 66% of the exchange sites were occupied by bases. With respect to base saturation Hartsells was in the intermediate position between Dewey and Sequoia on the one hand and Grenada on the other.

II. BASE SATURATION AND pH OF SOILS

Base saturation percentages and pH of the soil samples treated

with different amounts of lime are shown in table 4. The percent base saturation at different lime levels was calculated by adding the milliequivalents of bases in the untreated soils and the milliequivalents of Ca added as $CaCO_3$ and dividing the total by the cation exchange capacity as determined by the neutral normal NH_4OAc method. The pH values were determined 45 days after liming.

The pH values of Dewey, Hartsells, and Sequoia varied from 5.4 to 5.7. Grenada was more acidic than the above soils and had a pH of 4.6 which might be the reflection of high exchange acidity in this soil.

The effects of lime on pH of the Hartsells and Sequoia soils were about the same. One ton of lime per acre increased the pH of these soils 0.7 unit and an additional ton of lime increased the pH 0.5 unit. The increase in pH when two more tons of lime were applied was only 0.6 unit or 0.3 unit per ton of lime. The increase in pH of the Dewey soil was similar to Hartsells and Sequoia with the exception that 1-ton rate increased the pH of Dewey only 0.5 unit. The influence of lime on the pH of Grenada was somewhat different. The 1-ton rate of lime increased the pH only 0.3, the second ton increased the pH 0.8 and the application of two additional tons of lime increased the pH 0.65 of a unit per ton of lime. In all the soils the increase in rate of lime from 4 to 6 tons per acre did not greatly affect the pH values.

The pH values and base saturation of the unlimed samples of Dewey and Sequoia were similar. Both of these soils would have a pH of about 7.0 at 100% base saturation. The pH values of the Grenada samples were lower than those of the above two soils at low base saturations. However,

Table 4.--Base saturation and pH of soils treated with different amounts of calcium carbonate.

Soil Series	Lime T./A.	Base saturation* Percent	pH**	pH change due to each increment of $CaCO_3$	
				Total	Per ton of $CaCO_3$
Dewey	0	58.1	5.7	-	-
	1	76.2	6.2	0.5	0.50
	2	96.4	6.8	0.6	0.60
	4	113.1	7.3	0.5	0.25
	6	166.3	7.3	0.0	0.00
Grenada	0	44.1	4.6	-	-
	1	61.9	4.9	0.3	0.30
	2	79.7	5.7	0.8	0.80
	4	97.4	7.0	1.3	0.65
	6	150.7	7.3	0.3	0.15
Hartsells	0	49.1	5.4	-	-
	1	80.8	6.1	0.7	0.70
	2	112.5	6.6	0.5	0.50
	4	144.2	7.3	0.7	0.35
	6	239.3	7.2	0.0	0.00
Sequoia	0	59.0	5.5	-	-
	1	75.2	6.2	0.7	0.70
	2	91.5	6.7	0.5	0.50
	4	107.7	7.3	0.6	0.30
	6	156.5	7.3	0.0	0.00

*Initial bases plus calcium added as $CaCO_3$.

**Measured in 1:1 soil-water ratio, unleached samples; 45 days after lime application.

the pH increased greatly as the base saturation was increased to about 100%. The rate of change of pH of the Hartsells samples with an increase in base saturation was somewhat less than the other soils. At 100% saturation the pH for this soil would be expected to be about 6.2 compared to a pH of about 6.9 to 7.1 for the other three soils.

The pH of the unlimed and limed soils determined after leaching the samples and in 0.01 M $CaCl_2$ is not reported here; however, for the leached samples pH increase was from 0.3 to 0.9. For the samples in $CaCl_2$ the decrease was 0.1 to 0.5.

III. YIELD

The forage and root yields of alfalfa and the yield of lespedeza are presented in tables 5 and 6.

Applications of lime at various rates had different effects on the yields from the four soils and as was pointed out in the previous section, the soils vary greatly in their properties. The effect of lime as reflected on the yields of the two forage crops is, therefore, enumerated separately for each soil in the succeeding paragraphs.

Dewey

The average total yield of alfalfa forage was not greatly affected by the rate of lime, the yield varying within a very narrow range of 7.40 to 7.64 g. per can. Although the forage yield in the second cutting increased slightly with an increase in lime, this trend was not observed in the other two cuttings.

Table 5.--Forage and root yields of alfalfa grown on surface soil samples from four series treated with different amounts of lime.

Treatments		Forage, g./can*				Roots
Soil Series	Lime T./A.	1st cutting	2nd cutting	3rd cutting	Total	g./can*
Dewey	1	3.17	1.42	2.81	7.40	4.11
	2	3.32	1.51	2.81	7.64	4.38
	4	3.13	1.60	2.88	7.61	4.53
	6	3.07	1.76	2.78	7.61	4.09
	Mean	3.17	1.57	2.82	7.57	4.28
Grenada	1	1.71	0.16	0.30	2.17	1.14
	2	2.92	0.68	1.82	5.42	1.99
	4	3.34	1.16	3.17	7.67	3.82
	6	2.95	1.37	3.37	7.69	4.33
	Mean	2.73	0.84	2.16	5.74	2.82
Hartsells	1	3.37	1.62	3.57	8.56	3.75
	2	3.18	1.08	2.75	7.01	2.87
	4	3.07	1.08	2.57	6.72	3.21
	6	2.84	1.17	1.98	5.99	2.78
	Mean	3.12	1.24	2.72	7.07	3.15
Sequoia	1	3.00	0.99	1.75	5.74	1.90
	2	2.99	1.45	2.97	7.41	3.84
	4	3.65	1.35	3.26	8.26	3.68
	6	3.43	1.39	3.19	8.01	3.12
	Mean	3.27	1.29	2.79	7.35	3.13
L.S.D. for treatments						
	5%	0.48	0.53	0.79	1.33	1.34
	1%	0.64	0.72	1.06	1.79	1.80

*Average of three replications.

Table 6.--Forage yield of lespedeza grown on surface soil samples from four series treated with different amounts of lime.

Treatments		
Soil Series	Lime T./A.	Forage, g./can*
Dewey	1	4.88
	2	4.57
	4	4.11
	6	3.54
	Mean	4.27
Grenada	1	3.18
	2	4.75
	4	3.14
	6	1.65
	Mean	3.18
Hartsells	1	3.25
	2	3.51
	4	2.67
	6	2.35
	Mean	2.95
Sequoia	1	4.82
	2	4.65
	4	4.23
	6	4.38
	Mean	4.52
L.S.D. for treatments		
	5%	0.67
	1%	0.89

*Average of four replications.

There was, likewise, little effect of lime on the root yield of alfalfa. The yields varied from 4.09 to 4.53 g. per can with different lime levels. Root yields obtained in this soil were high compared to those produced in the other three soils.

Highest yield of 4.88 g. per can of lespedeza forage was obtained with 1-ton lime rate and the yield decreased with increased lime level. The lowest yield or 3.54 g. per can was obtained with 6 tons of lime.

Grenada

The average forage yield of alfalfa, in general, increased with lime in the different cuttings. The lowest yield of 0.16 g. was obtained with 1 ton of lime in the second cutting whereas the 6-ton lime rate produced the highest yield of 3.37 g. per can of forage in the third harvest.

The total forage yield of alfalfa increased from 2.17 g. per can with 1 ton of lime to 5.42 g. per can when the lime level was raised to 2 tons, an increase in yield by two and one half times. The total yield also increased significantly with 4 tons and 6 tons compared to that obtained with 2 tons. The yields at the 4- and 6-ton rates were about equal. The yields at these lime rates were equal to the yields from Dewey.

Lime had a similar effect on the root yield of alfalfa. The root yield was 1.14 g. per can for the 1-ton lime rate and reached a maximum yield of 4.33 g. per can when the lime was increased to 6 tons per acre.

The forage yield of lespedeza increased significantly from 3.18 g. per can with 1 ton to lime to 4.75 g. per can when the lime level was

raised to 2 tons per acre. Further increase in lime beyond 2 tons decreased the yield. A forage yield of only 1.65 g. per can was obtained with 6 tons lime which was about one-third the forage yield produced at the 2-ton rate.

Hartsells

One ton of lime per acre produced the highest yield of alfalfa in each of the three cuttings and the yield declined with an increase in the lime rate. The decrease was most pronounced in the third cutting. Highest yield of 3.57 g. of forage per can was obtained with 1 ton of lime for the third cutting and the yield went down to 1.98 g. per can when the lime level was increased to 6 tons per acre.

The effect of lime on the root yield was similar to that observed in the case of forage. The yield of 3.75 g. per can, the highest yield for the soil, was obtained with 1 ton of lime and the yield was reduced to 2.78 g. per can when the rate of lime increased to 6 tons per acre.

The effect of lime on the yield of lespedeza was similar to that observed in Grenada. The yield increased from 3.25 g. per can to 3.51 g. per can when the lime level was increased from 1 to 2 tons per acre. Further increase of lime decreased the forage yield of lespedeza and at 6-tons rate the yield was only 2.35 g. per can.

Sequoia

The average total yield of alfalfa forage increased significantly from 5.74 g. per can with 1 ton of lime to 8.26 g. per can with 4 tons of lime per acre. Further increase of lime to 6 tons, however, did not

influence the yield.

Lime had similar effect on the root yield of alfalfa. Yield increased with lime up to the 2-ton level. Higher rates of lime decreased the root yields slightly.

Highest yield of 4.82 g. of lespedeza forage per can was obtained with the lime rate of 1 ton, and there was a small but insignificant decrease in yield with the other lime rates.

IV. COMPOSITION OF PLANT MATERIAL

The percent Ca, Mg, K, P, the cation content and the Ca:Mg ratios of the first and third cutting of alfalfa and of lespedeza forage are given in tables 7 through 11.

On account of the different influence of lime on the composition of the plants grown on the four soils, the main observations are presented separately for each soil as in the previous section.

Dewey

Lime had little effect on the phosphorus content of alfalfa forage and the P percentage was about 0.25 at all levels of lime.

The percent calcium in the forage increased with rate of lime and the effect was seen more in the third cutting than in the first. The calcium content increased from 2.95% with 1 ton of lime to 3.18% with the 6-ton rate for the third harvest.

The Mg content decreased slightly with increase in lime up to 4-ton rate and there was a slight increase with 6 tons compared to that found with the 4-ton level in both the cuttings. The percent Mg at each

Table 7.--Mineral composition of first cutting of alfalfa grown on surface soil samples from four series treated with different amounts of lime.

Treatment		Composition of plant material*			
Soil Series	Lime T./A.	P %	Ca %	Mg %	K %
Dewey	1	0.25	2.28	0.23	2.28
	2	0.25	2.40	0.21	2.52
	4	0.25	2.61	0.19	2.52
	6	0.24	2.60	0.22	2.56
	Mean	0.25	2.47	0.21	2.60
Grenada	1	0.26	2.09	0.49	3.35
	2	0.24	1.87	0.32	3.24
	4	0.24	2.20	0.28	2.98
	6	0.22	2.41	0.32	3.10
	Mean	0.24	2.14	0.35	3.17
Hartsells	1	0.28	2.28	0.18	3.29
	2	0.27	2.32	0.23	2.99
	4	0.34	2.61	0.15	3.01
	6	0.35	2.73	0.17	3.07
	Mean	0.31	2.48	0.18	3.09
Sequoia	1	0.25	2.32	0.30	3.16
	2	0.26	2.42	0.25	3.07
	4	0.26	2.39	0.23	3.05
	6	0.24	2.38	0.21	3.02
	Mean	0.25	2.38	0.25	3.07
L.S.D. for treatments					
	5%	0.04	0.19	0.04	0.20
	1%	0.05	0.25	0.06	0.27

*Average of three replications.

Table 8.--Mineral composition of third cutting of alfalfa grown on surface soil samples from four series treated with different amounts of lime.

Treatment		Composition of plant material*			
Soil Series	Lime T./A.	P %	Ca %	Mg %	K %
Dewey	1	0.26	2.95	0.40	1.89
	2	0.26	2.97	0.33	1.81
	4	0.27	3.11	0.31	1.83
	6	0.28	3.18	0.36	1.95
	Mean	0.27	3.05	0.35	1.87
Grenada	1	0.49	2.42	0.70	3.51
	2	0.27	2.22	0.39	3.54
	4	0.27	2.45	0.33	3.33
	6	0.29	2.50	0.36	3.30
	Mean	0.33	2.40	0.44	3.42
Hartsells	1	0.33	2.56	0.20	2.90
	2	0.39	2.47	0.18	3.17
	4	0.50	3.02	0.17	3.52
	6	0.53	3.27	0.11	3.95
	Mean	0.44	2.83	0.16	3.38
Sequoia	1	0.34	2.57	0.40	2.84
	2	0.30	2.62	0.32	2.87
	4	0.29	2.55	0.24	3.03
	6	0.27	2.50	0.21	2.89
	Mean	0.30	2.56	0.29	2.91
L.S.D. for treatments					
	5%	0.06	0.40	0.08	0.42
	1%	0.08	0.55	0.11	0.56

*Average of three replications.

Table 9.--Mineral composition of lespedeza grown on surface soil samples from four series treated with different amounts of lime.

Treatment		Composition of plant material*			
Soil Series	Lime T./A.	P %	Ca %	Mg %	K %
Dewey	1	0.25	2.03	0.25	1.09
	2	0.27	2.30	0.24	1.12
	4	0.31	2.54	0.25	1.02
	6	0.29	2.68	0.26	1.03
	Mean	0.28	2.39	0.25	1.06
Grenada	1	0.25	1.70	0.34	1.24
	2	0.25	1.62	0.27	0.96
	4	0.30	2.15	0.35	1.03
	6	0.36	2.35	0.38	1.13
	Mean	0.29	1.95	0.33	1.09
Hartsells	1	0.29	1.99	0.21	1.30
	2	0.31	2.21	0.18	1.23
	4	0.38	2.55	0.10	1.21
	6	0.41	2.66	0.20	1.23
	Mean	0.35	2.35	0.17	1.24
Sequoia	1	0.27	1.72	0.30	1.22
	2	0.27	1.80	0.23	1.26
	4	0.32	2.04	0.26	1.36
	6	0.29	2.15	0.24	1.31
	Mean	0.29	1.93	0.26	1.29
L.S.D. for treatments					
	5%	0.04	0.15	0.05	0.07
	1%	0.05	0.20	0.06	0.10

*Average of four replications.

Table 10.--Total cation content and calcium-magnesium ratios of first and third cuttings of alfalfa grown on surface soil samples from four series treated with different amounts of lime.

Treatments		Total cations* me./100 g.		Ca:Mg ratio	
Soil Series	Lime T./A.	1st cutting	3rd cutting	1st cutting	3rd cutting
Dewey	1	205.2	228.9	5.93	4.44
	2	201.7	221.6	6.95	5.46
	4	210.1	228.0	8.49	6.03
	6	213.3	237.9	7.29	5.41
	Mean	207.6	229.1	7.09	5.28
Grenada	1	230.7	268.4	2.57	2.09
	2	202.2	233.3	3.58	3.45
	4	209.5	234.8	4.72	4.46
	6	225.9	238.4	4.63	4.25
	Mean	217.0	243.7	3.69	3.26
Hartsells	1	212.8	218.2	7.69	7.76
	2	211.9	219.1	6.05	8.32
	4	220.2	254.8	10.35	10.78
	6	228.8	273.7	9.97	17.53
	Mean	218.4	241.4	8.33	11.10
Sequoia	1	221.2	233.7	4.76	3.94
	2	216.5	231.0	7.14	4.92
	4	216.6	224.2	6.33	6.54
	6	213.3	216.0	6.88	7.10
	Mean	216.9	226.2	6.14	5.29

*Average of three replications.

Table 11.--Total cation content and calcium-magnesium ratios of lespedeza grown on surface soil samples from four series treated with different amounts of lime.

Treatment			
Soil Series	Lime T./A.	Total cations* me./100 g.	Ca:Mg ratio
Dewey	1	149.7	4.98
	2	163.1	5.81
	4	173.8	6.12
	6	181.3	6.25
	Mean	167.0	5.79
Grenada	1	144.7	3.04
	2	127.7	3.64
	4	162.9	3.67
	6	177.4	3.72
	Mean	153.2	3.52
Hartsells	1	150.4	5.62
	2	156.7	7.57
	4	167.0	14.74
	6	180.4	8.17
	Mean	163.6	9.02
Sequoia	1	141.4	3.50
	2	141.3	4.64
	4	158.3	4.66
	6	160.9	5.32
	Mean	150.5	4.53

*Average of four replications.

lime level for the third cutting was nearly one and one half times the Mg content found in the first cutting. The Mg content varied from 0.19 to 0.23% in the first cutting and from 0.31 to 0.40% in the final harvest.

Except for the slightly higher content with the 1-ton lime rate, the percent K remained about the same with different lime levels. Contrary to the trend observed in the case of Mg the general level of K at each lime level was lower in the third cutting than in the first harvest.

Total cations expressed as me. per 100 g. of plant material remained within a narrow range in both the cuttings analyzed. The Ca:Mg ratio of alfalfa forage varied from 5.93 to 8.49 in the first cutting and from 4.44 to 6.03 in the third harvest with different rates of lime. Although there was some variation in the ratios, the range was narrower than those found in alfalfa grown on the other soils, especially Grenada.

The phosphorus content of lespedeza remained about the same with different rates of lime and ranged between 0.25 and 0.31%. The Ca content of lespedeza increased with increase in rate of lime and the percentages of Ca for 1, 2, 4 and 6 tons of lime were 2.03, 2.30, 2.54 and 2.68, respectively. The Ca content of the lespedeza was less than that found in the alfalfa. The Mg content was about the same for all lime levels and was near 0.25 per cent. The K content of the lespedeza was affected little by lime and the percentage of K of the lespedeza was only one half the amount in the alfalfa.

The total cations varied from 149.7 to 181.3 me. per 100 g. of plant material and the range was comparatively wide. The total cation content of the lespedeza was much less than in alfalfa. The Ca:Mg ratios varied from 4.98 to 6.25 with different levels of lime and the

range was comparatively narrow as was the case with alfalfa on this soil.

Grenada

The phosphorus content of alfalfa in the first cutting was not greatly affected by rate of lime. In the third cutting the percent P with one ton of lime was 0.49 and was reduced to 0.27 to 0.29% at the other lime levels.

When the lime was increased from 1 to 2 tons per acre the Ca decreased from 2.09 to 1.87% in the first cutting and from 2.42 to 2.22% in the third harvest. With 4 and 6 tons of lime, however, the Ca content in both the cuttings increased over that found with 2 tons. The Mg content with 1 ton of lime was 0.49% in the first cutting and 0.70% in the third harvest. These amounts greatly exceeded the Mg content of the forage with the other levels of lime which varied from 0.28 to 0.32% Mg in the first cutting and from 0.33 to 0.39% in the third harvest. Lime had little effect on the K content of alfalfa forage in either cutting.

The total cation content of forage in both the cuttings was highest with the 1 ton of lime rate due to a high percentage of Mg and Ca found in forage at this rate of lime. The total cations with higher levels of lime, however, were not greatly different.

The Ca:Mg ratio was 2.57 with the 1-ton rate, increased with rate of lime and reached a maximum value of 4.72 in the first cutting with 4 tons of lime. The ratios were also increased in the third cutting. The corresponding values with 1 and 4 tons of lime were 2.09 and 4.46,

respectively. These values are low as compared to the ratios found in plants grown on Dewey.

The P content of lespedeza was unaffected with the application of 2 tons of lime per acre. However, the percent P increased from 0.25 with 1 and 2 tons lime to 0.36 with 6 tons of lime per acre.

The Ca content with 1 ton of lime was 1.70% which slightly decreased to 1.62% with 2-ton rate. Further increases in lime increased the Ca content and attained the value of 2.35% with 6 tons of lime per acre. The calcium content of lespedeza was slightly less than that of alfalfa.

Trends similar to those for Ca were observed in the case of Mg and K. The Mg percentage was reduced from 0.34 with 1 ton to 0.27 with the 2-ton rate. The Mg increased to 0.38% with the application of 6 tons of lime per acre. The K content was 1.24% with 1 ton which was reduced to 0.96% with 2-ton rate and increased to 1.13% with 6 tons of lime per acre. The K content of lespedeza was less than the amount in the alfalfa.

There was a wide variation in the total cation content of lespedeza. The total cations in general were lower than those found in alfalfa. For lespedeza the Ca:Mg ratios were about the same with different rates of lime. The values were lower than the ratios for Dewey.

Hartsells

The P content of alfalfa was about the same at 1- and 2-ton lime rate in both the cuttings but increased significantly with 4 and 6 tons

of lime per acre. The percentage of P at each lime level was greater in the third cutting than in the first.

The Ca content of the alfalfa increased with level of lime and the Ca percentages in the first cutting with 1, 2, 4 and 6 tons of lime were 2.28, 2.32, 2.61 and 2.73, respectively. The corresponding values, at each level of lime, however, were somewhat higher in the third cutting.

The Mg content of forage in general was low and there was a reduction in Mg percentage with increasing rate of lime. The decrease was more pronounced in the third cutting where the Mg content was reduced from 0.20% with 1 ton of lime to 0.11% with the application of 6 tons of lime per acre. The K content was affected little by lime in the first cutting but in the third cutting the K percentage increased from 2.90 with 1 ton of lime to 3.95 with 6 tons.

The total cations varied widely especially in the third cutting. The Ca:Mg ratios increased significantly with lime and the range was wide in the case of the third cutting where the ratio varied from 7.76 with 1 ton to 17.53 with 6 tons of lime.

The P content of lespedeza increased with lime. The percentage P went up from 0.29 with 1 ton to 0.41 with 6 tons of lime. The Ca content, likewise, increased with lime and the percent Ca with 1, 2, 4 and 6 tons of lime was 1.99, 2.21, 2.55 and 2.66, respectively.

The general level of Mg of the lespedeza was very low with all lime rates as in the case of alfalfa forage and there was a tendency for the Mg to decrease slightly with the increase in the rate of lime.

The percent K was affected little by lime rate and varied from 1.21 to 1.30% with different rates of lime per acre. On Hartsells, as with the other soils the K content of lespedeza was low compared to that in alfalfa.

The Ca:Mg ratios of lespedeza increased with lime and the difference between the minimum and maximum values was quite large.

Sequoia

Lime had little effect on the P content of alfalfa forage with the percentage P in the various lime treatments varying from 0.24 to 0.26 in the first cutting and from 0.27 to 0.34 in the third harvest.

The Ca content varied from 2.32 to 2.42% in the first cutting and from 2.50 to 2.62% in the third cutting with different rates of lime. There was, however, a small reduction in Mg content with increase in lime rates and the percentages of Mg for 1, 2, 4 and 6 tons of lime per acre were 0.30, 0.25, 0.23 and 0.21, respectively, in the first cutting. A similar reduction in Mg content with increase in lime level was observed in the third cutting also. There was little effect of lime on the K content of alfalfa forage in either cutting.

The total cation content of the alfalfa was not greatly affected by rate of lime application. The Ca:Mg ratio increased with lime and the values were comparable to those found in Dewey.

The P content of lespedeza was about the same with different lime levels except for a slight increase in percent P with 4 tons of lime. The Ca content increased with lime and varied from 1.72% with 1 ton to

2.15% with 6 tons of lime. The Mg in lespedeza with 1 ton of lime was 0.30% and this value was slightly higher than those found with higher levels of lime. There was little difference in the Mg contents with 2, 4 and 6 tons of lime. The K content was 1.22% with 1 ton lime and was slightly higher with increased rate of lime per acre. The percentage K at all levels of lime was lower than in alfalfa as was observed in other soils.

The total cation contents of lespedeza were higher at the 4- and 6-ton lime rates than at the 1- and 2-ton rates. The Ca:Mg ratio increased slightly with increases in lime rates.

CHAPTER V

DISCUSSION

The results of this study bring out a few interesting points regarding the effects of some of the soil properties on the lime requirements of the different soils and also on the yield and composition of the forage crops.

As stated by Pearson (31) the role of lime in the correction of the undesirable effects of soil acidity on plant growth is probably the most complex one to be found in soils. He mentions that lime will have one or more of the following effects on plant growth: supplying Ca and Mg as nutrients, maintaining availability of applied nutrients, improving availability of native soil nutrients, enhancing desirable types of microbial activity, improving plant root development and reducing toxic effects of Mn and Al.

Arnon and Johnson (2) working with nutrient solutions and sand cultures have shown that many plant species grow normally at pH values as low as those found in most acid soils. Further, as pointed out by Truog (40), the root sap of most common plants has a pH ranging from 4.0 to 6.0. It is evident that the H ions per se are not toxic to plants and the main benefit of liming is not in its effect on the reduction of the concentration of H ions in the soil.

In this study the Ca content of alfalfa forage increased with increases in the rate of lime applied to Dewey and Hartsells soils, but there was little effect of lime on the percent Ca in alfalfa on Sequoia.

On Grenada the Ca content of forage increased with lime rates of 2 to 6 tons per acre, but the percent Ca was higher with 1 ton than with the 2 tons. The Ca content of lespedeza on Dewey, Grenada and Hartsells followed the same trend as of alfalfa. The percentage Ca of lespedeza on Sequoia increased with the increase in lime rate.

Comparing these results with the forage yields of alfalfa and lespedeza shown in tables 5 and 6, it is observed that the uptake of Ca is not necessarily correlated with increase in yield in these soils. For example, even though the Ca content of both the forage crops grown on Dewey increased with lime, the yield of alfalfa was unaffected by different rates of lime. On the other hand the yield of lespedeza decreased with increasing levels of lime. In Grenada the lowest yield was obtained with 1 ton of lime per acre but the Ca content of forage was higher than that obtained with the 2-ton lime level.

Peech and Bradford (32) have pointed out that many of the factors like Ca deficiency, toxicity of H, Al, and Mn might contribute to the response shown by crops to liming and the relative importance of these may vary with the nature of soil and crop. They considered that poor growth of many crops on acid soils may not be due to Ca deficiency brought about by a low saturation of Ca.

Results of the present study also bring out the fact that an increase in Ca content of forage has no direct bearing on the yields of alfalfa and lespedeza and that the increases in yield observed on some of these soils is probably not due to improvement of the Ca nutrition of the plants.

Stubblefield and DeTurk (38) working with corn, oats and wheat found that there was a general increase in the Ca content of the plant with liming. They also suggested that as P was transformed into organic tissue and became part of the plant, the uptake of P accompanied simultaneous growth of plants. This, they considered, would cause the percentage P of plants to remain unchanged greatly.

In the present study the P content of alfalfa forage was about the same with different lime applications to Dewey and Sequoia and the first cutting on Grenada. These results agree with the observations of Stubblefield and DeTurk. In the case of Hartsells the forage with 4 and 6 tons of lime per acre contained a higher percent P. The higher P content of the third cutting of forage in Grenada with 1 ton of lime might be due to the reduced growth caused by the toxic concentration of Al. In the case of Hartsells the growth of alfalfa with higher rates of lime was reduced due to some factor becoming unfavorable and thus might have caused the P to accumulate and result in a high percent P in the forage.

The higher content of P in forage grown on Grenada with 1 ton lime might also be due to the high content of Mg in the forage. Truog et al. (41) observed an increase in the level of P in peas with an increase in the content of Mg and considered their results as confirmation of the theory that Mg functions as the carrier for P. However, this explanation does not hold for Hartsells where the increase in P content corresponds to the decrease in Mg percentage of alfalfa forage.

Table 2 shows that Grenada contains more than 2.5 me. of

exchangeable Al per 100 g. of soil. The Al content was reduced to about half this value with 1 ton of lime and was reduced to a very low level only when 4 tons of lime were applied. Yields of alfalfa on this soil increased as the exchangeable aluminum was reduced. This indicates that one of the major causes of low yield in Grenada was Al toxicity.

The growth of roots of alfalfa followed very much the same trend as the forage. Reduction in exchangeable Al content of the soil favored better root development. This is in agreement with the findings of Ragland and Coleman (34). While studying the root growth of sorghum they found that the weight of roots decreased as the percent Al saturation in the soil increased. Roots grew well in each subsoil when lime was applied.

Foy (11) working with four soils of Arkansas found that liming the soils to approximately pH 6 reduced the levels of extractable Al and exchangeable Mn and increased levels of exchangeable Ca in the soil. He considered that the difference in levels of extractable Al did not adequately explain the wide difference in yield of alfalfa and pointed out that liming appeared to be more closely related to decrease in exchangeable Mn and increase in Ca saturation than to decrease in exchangeable Al.

Since no determinations of either exchangeable Mn in the soil or Mn content of the forage were made in this study, the influence of lime on Mn availability or uptake is not known. In an experiment Vlamis (42), however, found that there was no depressing effect on yield of barley when $MnSO_4$ was added to the displaced solution from a limed soil but

the yield was reduced considerably when aluminum sulphate was added to the solution. Since the increase in yield of alfalfa in this study followed closely the reduction of exchangeable Al it is to be inferred from the data that exchangeable Al could be one of the major causes for the low yields of alfalfa in the Grenada and Sequoia soils at low lime rates.

The exchangeable Mg in Hartsells was extremely low and the application of lime caused a high exchangeable Ca:Mg ratio in the soil. Hunter (15), working with a soil with different Ca:Mg ratios, found that Ca in the forage of alfalfa increased as the Ca:Mg ratio in the soil was changed from 1:4 to 4:1 and that further increase in the ratio had very little effect on the Ca content of the forage. He further observed that Mg in the forage decreased rapidly as the amount of Mg in the soil decreased and the Ca:Mg ratio of the soil increased.

In the present study there was a considerable reduction in the Mg content of the third cutting of alfalfa on Hartsells as the rate of lime increased. The values were well below the critical Mg content of 0.24 per cent as suggested by Bear and Wallace (4) for alfalfa. The yield of the third cutting was reduced from 3.57 g. at the 1-ton lime rate to 1.98 g. at the 6-ton rate. Magnesium deficiency symptoms were observed on alfalfa leaves during the third growth. This suggests that the reduction in yield of alfalfa on Hartsells with increased rate of lime was probably due to Mg deficiency.

Bear and Prince (3) observed that the total cations Ca, Mg and K expressed as me. per 100 g. of alfalfa forage grown on soils limed

to pH 7.0 with $CaCO_3$ were approximately constant in any harvest. Thorp and Hobbs (39) working with a soil from Kansas found that the total cations in alfalfa tended to be approximately constant and varied between 185-200 me. per 100 g. of alfalfa forage.

In this study, with a few exceptions, the total cations for each soil tended to be approximately constant irrespective of the rate of lime applied. The total cations in plants were considerably higher in the case of Grenada with 1 ton lime than either of the other rates. In Hartsells the total cations were highest at the 6-ton rate.

Halstead et al. (13) applied different quantities of $CaCO_3$ and $MgCO_3$ to two surface soils and grew alfalfa in a greenhouse. They found that the Ca:Mg ratio established in the soil by the addition of carbonates was reflected in the Ca:Mg ratios of alfalfa. The low Ca:Mg ratio in the plants grown with applied P and an excess of $MgCO_3$ in Mountain sandy loam was related to the low exchangeable Ca:Mg ratio in the soil and to a low yield compared to that obtained with excess of $CaCO_3$.

In this study, Grenada with a high content of exchangeable Mg compared to exchangeable Ca had a very low Ca:Mg ratio which widened as the rate of lime application increased. There was a corresponding increase in the Ca:Mg ratio of alfalfa from 2.09 to 4.46 as application of lime increased from 1 to 4 tons per acre. The highest yield of alfalfa was obtained when the Ca:Mg ratio in the plant and in the soil was not low. This is in line with the findings of Halstead et al. (13).

In the case of Hartsells, however, the exchangeable Ca:Mg ratio in the unlimed soil was high because of a low content of exchangeable

Mg. The ratio in the soil widened with addition of lime. The Ca:Mg ratio in the plant increased and the yield decreased with an increase in the ratio of Ca:Mg in the soil.

It thus appears that the yield of alfalfa is adversely affected by too low or too high Ca:Mg ratios in the soil.

McLean and Cook (22) found that in 5 out of 6 soils studied, liming the soil to pH 7.5 increased the yield of alfalfa in the absence of the application of phosphorus. When P was applied to the soil the optimum pH range was between 6.5 to 7.0. Soil pH within this range has been found by other workers (10, 11, 22) to produce near maximum yields of alfalfa. In this study the highest yields were obtained when the pH was 6.8 to 7.3 except in the case of Hartsells where the highest yield was obtained when the soil had a pH of 6.1. This, however, does not rule out the probability of obtaining higher yields of alfalfa at a soil pH of 6.5 or above in Hartsells if adequate Mg is applied to the soil.

The pH increased more in Dewey and Sequoia than in the other two soils with an increase in base saturation. This may be due to the low content of exchangeable acidity in these soils or to the type of clay minerals. In Grenada the rate of rise in pH was low at low base saturations but once the exchangeable acidity or the extractable Al were neutralized, the increase in pH was more with the increase in base saturation. Although in Hartsells the pH rise to about 6.0 was as high as in Dewey and Sequoia, the base saturation had to increase to a relatively high level before the pH of this soil reached 6.5. The

high percentage of organic matter might be responsible, to a certain extent, for the behavior observed in Hartsells.

The present lime recommendation for soils of Tennessee is to apply 1 ton of agricultural lime for each 0.5 unit pH change desired. Since agricultural lime frequently is not quickly soluble, a factor of two is used to convert the quantity of calcium carbonate to agricultural lime. The pH changes in this study suggest that the application of 1 ton of lime may change the pH value by only 0.15 to 0.35 unit and that the amount of change depends upon the pH of the unlimed soil and the properties of the soil.

The yield pattern of lespedeza is different from that of alfalfa. The variations in the yields on the different soils can be explained only partly on the lines stated in the case of alfalfa. For example, the increase in yield of lespedeza in Grenada and Hartsells as the lime rate increased from 1 ton to 2 tons may be explained on the basis of the reduction in the content of exchangeable Al. However, the chemical composition does not indicate the reason for the reduction in yield where lime was increased to 4 and 6 tons per acre on these soils or to 2, 4 or 6 tons on Dewey.

Moser (28) obtained the highest yield of Korean lespedeza at a soil pH range of 5.0 to 5.5, but no explanation is offered by him for the maximum yield at this relatively low pH.

Additional research is necessary before the causes for the variation in the lespedeza yields on three of these soils can be explained.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Two experiments were set up in greenhouse, one with alfalfa and the other with lespedeza using four soils treated with 1, 2, 4 and 6 tons of lime per acre. The samples used were surface soils from Dewey silty clay loam, Grenada silt loam, Hartsells sandy loam and Sequoia silt loam.

Three cuttings of alfalfa and one cutting of lespedeza were made. The root yield of alfalfa was also obtained after the final harvest.

Soil and plant material were analyzed and the periodic change in the pH of the limed soils was determined to evaluate the influence of some of the soil properties on the lime requirement of these soils and to study the effect of different rates of lime application on the yield and composition of the forage crops grown.

The findings of this investigation are briefly outlined below:

1. Each soil was different in its physical and chemical properties and also in its ability to produce the forage crops with different levels of lime.

2. Lime at rates greater than 1 ton had little effect on the forage and root yield of alfalfa on Dewey. High exchangeable Ca, high base saturation and low exchange acidity were the factors considered reponsible for this behavior of the soil.

3. The yield of alfalfa forage and roots increased with lime rates up to 4 tons on Grenada. This soil had comparatively low

exchangeable Ca, high exchangeable aluminum and low base saturation. The toxicity of exchangeable Al was considered the main cause of poor growth of alfalfa with low levels of lime and the high yield obtained with application of 4 or 6 tons of lime per acre was attributed to the reduction of exchangeable Al to a very low level at these rates of lime. The more favorable soil Ca:Mg ratio and improved Ca nutrition at the high lime rates may also have contributed to the higher yields at the two high lime levels.

4. Maximum yields of alfalfa forage and roots were obtained in Hartsells with 1 ton lime and the yield decreased with further application of lime. Exchangeable Al was reduced to a low level with only 1 ton of lime in this soil which may have facilitated the production of a good yield of alfalfa. Considerable reduction in yield with increased lime level was thought to be due to Mg deficiency as may be inferred from the very low exchangeable Mg content in the soil, low Mg percent in the forage and the Mg deficiency symptoms observed during the third growth of the alfalfa.

5. The yield of alfalfa in Sequoia was significantly increased up to the lime rate of 2 tons per acre, and this increase in yield may be due to the reduction of exchangeable Al to a non-toxic level.

6. Increased Ca content of forage did not necessarily follow the increased forage yields.

7. The Ca:Mg ratio in the soil was reflected on the Ca:Mg ratio in the plant. Too narrow or too wide a Ca:Mg ratio in the soil or plant was associated with low yields of alfalfa on Grenada and Hartsells.

8. Highest alfalfa yields were obtained within a soil pH range of 6.8 to 7.3 except in the case of Hartsells where the yield was highest with the pH value of 6.1.

9. The rise in pH with the increase in base saturation varied in the different soils. The more rise in pH with the increase in percent base saturation in Dewey and Sequoia was considered due to the low content of exchangeable Al in these soils. Similarly, the reason for low pH rise in Grenada was attributed to the high amount of exchangeable Al. In the case of Hartsells, the high content of organic matter was probably responsible for the low rise in pH with increased base saturation.

10. The yield pattern of lespedeza differed from that of alfalfa. The yield increased with the application of 2 tons of lime over 1-ton rate in Grenada and Hartsells. This might be due to the reduction in exchangeable Al in the soil. But it is difficult to explain the significant decrease in yield on these soils when additions of 4 and 6 tons of lime per acre were made. Similarly, the decrease in yield with the increase in lime rate in Dewey and Sequoia is also inexplicable.

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