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To the Graduate Council:

I am submitting herewith a thesis written by Madathilettu Mathai Koshy entitled "The Influence of Lime and Phosphorus Application to Three Soils on Yield and Nutrient Uptake by Sorghum." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

Lloyd L. Lentz
Major Professor

We have read this thesis
and recommend its acceptance:

W L Parks

Robert S. Dotson

Accepted for the Council:

W. E. Spivey
Acting Dean of the Graduate School

THE INFLUENCE OF LIME AND PHOSPHORUS APPLICATION TO THREE SOILS ON YIELD AND NUTRIENT UPTAKE BY SORGHUM

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

Madathilettu Mathai Koshy

December 1960

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CHAPTER I

INTRODUCTION

In this age of industrialization and technological advancement, the importance of maintaining the efficiency of agricultural production at the highest possible level cannot be overemphasized. Although the mechanization of farming operations and the widespread use of commercial fertilizers, insecticides and herbicides have helped to increase agricultural production in this country substantially, the indiscriminate use of these modern means is apt to be followed by undesirable consequences. This situation, therefore, necessitates the conduct of agronomic experiments designed with a view to finding out the most intelligent way of using these soil amendments and at the same time conserving and improving the fertility of the soil. Greenhouse experiments have several advantages in this regard. They can be designed to include a large number of treatments and a wide variety of soils, and can be carried out at any time of the year irrespective of the seasons. Furthermore, greenhouse experiments are particularly adapted for investigating soil-plant relationships of a fundamental nature, which it would be difficult to study in the laboratory or in the field. One such relationship which has been studied over several decades is the influence of lime on acid soils in promoting the growth and uptake of nutrients by higher plants.

Lime is generally credited with a dual role in acid soils. Its direct function is to correct the soil acidity and improve the soil structure and thus create an environment suitable to the growth and

development of the roots. At the same time it performs several indirect functions as well. It stimulates microbiological activity in the soil, thereby increasing the availability of nitrogen, phosphorus and sulfur to plants. It reduces phosphate fixation, and helps to remove toxic concentrations of aluminum and manganese from the soil solution. In some soils at least, lime is responsible for enhancing the availability of potassium. Within the plant, too, lime performs several important functions. Calcium is essential for the growth of the meristems, especially for the development and functioning of the root tips. It is also considered that calcium is probably concerned with certain enzymes involved in respiration. Notwithstanding these many functions attributed to calcium, what is of immediate concern to the agronomist is its effect on the availability of other nutrients to plants, especially of phosphorus.

The importance of phosphorus availability in crop production is emphasized by the fact that a deficiency in this element is very often a limiting growth factor in many soil types. The problem of phosphate fertilization is also complicated by the phenomenon of "fixation" which renders phosphate fertilizers applied to soils unavailable to plants. At the same time phosphorus is a very critical element in nutrition inasmuch as it controls several vital, metabolic processes within the plant.

It would, therefore, be evident that fertilizer experiments involving the use of lime and phosphates on acid soils will be quite important in reaching conclusions regarding the judicious use of these

nutrients as well as fertilizers in general. This work was, then, undertaken with the following objectives in view:

(1) To study the influence of liming and phosphorus fertilization of different acid soils on the growth and uptake of phosphorus and cations by plants; and

(2) To study the influence of limestone and phosphate additions to different soils on the pH and phosphorus availability of the soils as measured by chemical means.

Three soils were used in this study, viz; a Hartsells loam (pH 4.6), a Dewey silt loam (pH 4.7) and a Grenada silt loam (pH 4.9). They were all very low in available phosphorus. They represent some of the major farming areas in this State. Sorghum was used as the indicator plant as it is well known for its sensitiveness to soil phosphorus availability. Details of the procedure adopted and the results obtained are presented and discussed on the subsequent pages.

CHAPTER II

REVIEW OF LITERATURE

Numerous workers have investigated the influence of lime on soil reaction and nutrient availability to crops by different techniques such as laboratory studies, greenhouse experiments and field trials. Comprehensive reviews of the earlier works have been made by Beeson (9) and also by Truog (39, 40) and no attempt will be made to review the entire literature on this subject, excepting those publications that have a direct bearing on the plan and interpretation of the results of this work. Attention is here focused on two relevant aspects of liming, viz., its effect on the soil reaction, phosphate availability and plant growth, and its influence on the cation equilibria in plants.

A. The Effect of Liming on Soil Reaction, Phosphate Availability and Plant Growth

Among the earlier works Salter and Barnes (28) observed that in the soils investigated by them, phosphate response declined as the soil reaction was changed from pH 5.0 to pH about 7.5. However, there was an indication that an increase in the availability of native soil phosphate took place as the reaction was made more and more alkaline up to this pH. According to Hutchings (17) calcium not only decreased the acidity of the soil complex, but also aided the plant in making more tissue and in absorbing a larger quantity of nutrients. It was found that when the calcium level was low applied phosphorus was efficient

only occasionally, but it was effective almost invariably at higher levels of calcium application.

Albrecht and Klemme (1) have reported field work in which the application of limestone and superphosphate almost doubled the calcium, phosphorus and protein content of lespedeza forage over that obtained from superphosphate alone. Their data also reveal that the absorption of phosphorus was increased by liming, and indicate that soils may be deficient in lime without crop yields being seriously affected.

Summarizing the results of experiments conducted over a period of four years in Illinois, Stubblefield and DeTurk (35) concluded that liming of the soils is generally reflected in an increased percentage of calcium in the plants. As phosphorus gets converted into living tissues and becomes part of the organic plant body the uptake of this element is accompanied by a corresponding growth and so the percentage of phosphorus is not influenced by additions of phosphatic fertilizers.

Davis and Brewer (13) found that the liming of certain upland soils in Louisiana enabled Austrian winterpeas and common vetch to utilize larger quantities of phosphorus supplied by applications of superphosphate. Lime alone produced an increase in the percentage content of calcium only while lime applied with superphosphate resulted in an increased content of calcium, phosphorus and nitrogen.

In an experiment on the effects of preliming with calcium carbonate and brief ageing upon the recovery of phosphorus from subsequent incorporations of water soluble calcium phosphate, MacIntire and Hatcher (20) observed that in every case the phosphate uptake from the prelimed

and aged soil exceeded that from the unlimed soil. However, MacIntire (19) viewed the heavy liming of the soil as being apt to generate too large a quantity of calcium salts and that a high concentration of soluble calcium compounds in the soil solution tended to diminish the solubility of basic calcium phosphates. The unavailability of tri-calcium phosphates in heavily limed soils was accounted for by the fact that the soil water dissolved the readily soluble calcium salts and lost most of its capacity to dissolve tricalcium phosphate. It was also suggested that heavy liming affected phosphate utility by causing a decrease in the boron content of the soil.

Neubauer's and Truog's tests conducted by Dunn (14) have shown that soil phosphorus becomes more and more available with increasing additions of lime up to slightly above the neutral point. Chemical analysis of the forage from a greenhouse experiment indicated that the supply of available calcium readily increased in proportion to the amount of lime applied. It was therefore concluded that the liming of acid soils in Western Washington to pH values of about 6 to 7 was most favorable to the growth of plants, as it tended to increase the supply of calcium and the availability of soil phosphorus for plant nutrition.

Beater (8) traced for a period of thirteen months the change in pH of seven representative soils of the sugar belt of Natal and Zululand consequent on the additions of calcium carbonate. The effect on the pH value appeared to depend on the physical composition of the soil and the native calcium already absorbed. When maize followed by sugar-cane was grown on the soils prelimed to varying pH values, it was found

that preliming resulted in a 20 percent increase in the concentration of nitrogen and calcium in the dry plant material.

Smith and Hester (32) found that the liming of an acid Putnam silt loam, too low in calcium, failed to increase the calcium content of soybeans, but produced a significant increase in the nitrogen and phosphorus content. Bear and Wallace (7) reported that an annual topdressing of 1,000 pounds of calcium carbonate per acre resulted in a definite increase in the yield of alfalfa.

In an experiment using superphosphate labeled with P^{32}, McAuliffe et al. (22) found that the phosphorus content of oats increased as a result of liming. The residual effect of phosphorus applied at such a high level as 2,000 pounds of superphosphate per acre was insufficient for maximum yields after a period of about eight years.

Stewart and Pearson (34) noted a tendency for plants to take up a lower percent of their phosphorus from the fertilizer under limed conditions than under unlimed conditions. The beneficial effects of a three ton application of calcium carbonate on the growth of clover was not more than that of a one ton application, nor was there any evidence of overliming injury.

In greenhouse experiments using radioactive phosphorus, Neller (23) found that the addition of lime to raise the pH of Rutlege fine sand from 5.61 to 6.76 had no significant effect on the percentage of the phosphorus taken up by oats from either sodium phosphate or from superphosphate. On Carnegie fine sandy loam, lime increased the uptake of phosphorus by oats, although not significantly. In a field

experiment on Marlboro fine sandy loam to which ground dolomitic limestone was disked into the surface layer at different rates, higher rates of application had no significant effect over an application of 500 pounds per acre. The phosphorus content of oats was not affected by higher levels of lime application, but it was increased when superphosphate was used in larger amounts.

Similar studies by Robertson et al. (27) showed that liming soils relatively low in residual phosphorus increased the availability of applied phosphorus up to a pH of about 6.0 or 6.5, when the sesquioxide content was high, but had no effect when the sesquioxides were low. Liming these soils to pH values above 6.5 caused the percentage of phosphorus in the plant from the fertilizer to level off or decline, possibly due to the formation of relatively unavailable tricalcium phosphate. Liming soils high in residual phosphorus reduced the availability of fertilizer phosphate, regardless of the sesquioxide content. The uptake of phosphorus from currently applied superphosphate was highest from the soils high in sesquioxide content irrespective of the rate of liming.

MacLean and Cook (21) reported that liming soils up to pH 7.5 increased the yields of alfalfa on five out of the six soils studied, when no phosphorus 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. Application of phosphorus resulted in appreciable increases in the yields 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.

Adams (2) also reported significant increases in sorghum grain and stover yields as a result of liming.

Lawton and Davis (18) studied the effects of liming two strongly acid Rifle peat soils on the growth and absorption of soil and fertilizer phosphorus by field beans, Sudangrass and corn under greenhouse conditions. It was observed that the dry weight of field beans was markedly increased by lime applications up to 12 tons of calcium carbonate per acre. The growth of corn, however, was depressed when more than 3 tons of calcium carbonate per acre were applied. Liming had little or no effect on the yield of Sudangrass. It was further noted that liming had a depressing effect on the phosphorus content of plants, which was attributed to a decrease in the proportion of the $H_2PO_4^-$ to the $HPO_4^=$ ions in the soil solution.

In a greenhouse experiment using acid soils from south central Kansas, Thorp and Hobbs (37) observed that the application of lime increased significantly the percentage of calcium in alfalfa. Liming had no apparent effect on the percent of phosphorus in the plant, but the uptake of phosphorus was greater from the limed than from the unlimed soils.

Ensminger and Pearson (15) investigated the residual effects of various phosphates as measured by yields, P^{32} uptake and extractable phosphorus on a Decatur silt loam and a Greenville fine sandy loam. For any particular source of phosphorus it was found that the residual

effects were in proportion to the amounts that had been added. Among the different fertilizer materials used, basic slag gave the highest residual effect on Decatur silt loam as measured by vetch and cotton yields, which was attributed to the neutralizing effect of this fertilizer material.

Pretty and McCall (26) investigated the effects of different liming materials on soil reaction and on the yield and phosphorus uptake of alfalfa. Calcium carbonate was the most effective in raising the soil pH, followed by dolomite and water quenched basic slag in order. Liming increased the yield of alfalfa on soils with low pH values, but no significant increases in yield occurred on soils which had an initial pH near 6.0 or above. The effect of lime upon the extractable phosphorus in the soil varied with the soil, the form of lime and the extracting method used. There was very little relationship between the phosphorus content of alfalfa and the extractable phosphorus in the soil.

The superiority of magnesium-bearing liming materials over other forms of lime has been recently stressed by many workers, especially on the European continent. Schmitt (29) reported that in field experiments on sandy and loam soils of pH 4.1 - 5.1, neutralization was better achieved, and higher yields of root crops and cereals were obtained with dolomitic limestone than with $CaO.MgO$, $CaCO_3$ or with CaO. According to Trénel and Schönberg (38) the magnesium content of alkaline fertilizers such as basic slag is beneficial to crops, but pot experiments comparing $MgCl_2$ and $MgSO_4$ with $MgCO_3$ indicated that benefit from Mg is obtained only when the Al ions have been removed from the soil solution by liming,

as for instance with dolomitic limestone. Nieschlag (24) observed that dolomitic limestone was superior to ordinary limestone in increasing yields in cereal-root crop rotation. Griffiths (16) has reported that magnesium limestone applied to frequently and heavily nitrogen fertilized grasslands increased the yield and magnesium content of the forage. Magnesium applied in the form of magnesite or magnesium sulphate was not as effective as that applied in the form of dolomite.

B. The Influence of Lime on Cation Equilibria in Plants

Several workers have observed a tendency for the sum of the various cations in plants expressed as milliequivalents per 100 g. of dried plant material to be a constant under a given set of conditions.

Van Itallie (43) found that the sum of Ca, Mg, Na and K in Italian rye grass grown in Mitscherlich culture vessels was approximately a constant, ranging from 182.5 to 215.0 me. per 100 g. Fourteen out of the 22 values were within the range of 195.0 to 205.0, and this worker concluded that the mutual replacement of cations in the plant was in nearly equivalent proportions. It was further observed that calcium did not cause any great variation in the composition of the plant and therefore did not play an important part in ion replacement. Magnesium, on the other hand, had a greater influence on the composition of plants, because from an equal application of calcium and magnesium, more magnesium than calcium was taken up.

After reviewing several works on the effect of soil type and fertilizer treatments on the chemical composition of certain forage and small grain crops, Vandecaveye (42) observed that among a variety of soil factors, differences in soil texture were most frequently claimed to be responsible for significant differences in the composition of legume hays and cereal grains.

The experiments of Stubblefield and DeTurk (35), referred to earlier, have shown that any variation in the soil supply of the cations tends to be reflected in the vegetative part of the plant. Thus, potassium which is not converted into organic substances in plant growth, tends to accumulate in the plant sap in soluble forms. Similarly, increased applications of lime are reflected in an increased percent of calcium in the plant. The use of dolomitic limestone was also found to be responsible for increased percentage of magnesium in the stover of corn. These authors did not, however, attempt to study the interrelationships between the cations.

Collander (12) cultivated plants of a number of species in nutrient solutions containing several cations in equivalent amounts, after which the plants were analysed for their cation composition. It was observed that the differences between plant species cultivated in a given solution were very unequal in regard to the different cations. Some species were rich in certain cations, while some other species contained more of some other cations. This author has stressed the very complex nature of the selective absorption of cations by the higher plants.

Beeson et al. (10) recorded that the phosphorus concentration of tomatoes was significantly and positively correlated with magnesium supply, whereas neither the potassium nor the calcium supplies were significant in their correlation with phosphorus concentration in the leaflets. In general there was positive correlation between the concentration of the cations in the plants and their supply, while there was negative correlation between calcium and potassium, and between calcium and magnesium.

Bear and Prince (5) also recorded a cation equivalent constancy in alfalfa. They grew the Atlantic variety of alfalfa in two-gallon quantities of soils limed to pH 7.0 with calcium carbonate and treated with standard applications of fertilizer. With repeated harvesting of the successive crops, the calcium and magnesium content of alfalfa tended to increase, whereas the content of potassium decreased. The sum of the equivalence of Ca, Mg and K contained in any harvest tended towards a constant. These authors, therefore, contend that each of these cations has at least two functions in the plant, one specific and the other or others of the type which can be performed interchangeably by all cations. Once the supply of a particular cation is adequate to meet the specific need for it, there can be a wide range in the ratios in the remaining quantities that are absorbed by the plant to meet its total cation requirements.

According to Snider (33) the chemical composition of plants depends upon a number of factors such as species, the stage of growth, seasonal conditions, the type and fertility of the soil on which the plant is grown,

insect injuries, diseases and other conditions. This worker observed that the percentages of P and K in both legumes and nonlegumes varied with the amounts of these available in the soils. When P and K were applied to the land there was, as a rule, an increase in the content of these elements in the hay.

Wittwer et al. (44) investigated the influence of nutrient element balance on the growth and production of vegetation in several vegetable crops. The growth responses by plants were found to be dependent on the relative proportion as well as absolute amounts of the various nutrient elements present in the substrate.

In the work referred to earlier, Thorp and Hobbs (37) reported that the total cation content in alfalfa ranged from 185 to 200 me. per 100 g. Lime applications significantly increased the percentage of Ca in the plant. The total uptake of Ca was also increased, but there was no significant difference in the total Mg or Mg percentage.

CHAPTER III

MATERIAL AND METHODS

The three soils used in this experiment were a Hartsells loam, a Dewey silt loam, and a Grenada silt loam. The chemical characteristics of these soils are given in Table 1. The liming material used was dolomitic limestone ground to pass through a 100 mesh seive. Phosphorus was applied in the form of monocalcium phosphate and a basal dressing of potash was given in the form of potassium sulfate. The treated soil was placed in plastic lined No. 10 cans and sorghum was seeded. Details of the procedure followed for the greenhouse experiment and for the laboratory studies are given separately below.

A. Greenhouse Experiment

Four rates of lime and four rates of phosphorus were used in this experiment in a factorial design with three replications on each of the three soils. The liming rates were 0, 2, 4 and 6 tons of dolomitic limestone per acre. In the light of previous experience that very little plant growth on Hartsells soils without the application of phosphorus is obtained, it was decided to avoid the 0 treatment for phosphorus. The rates of phosphorus application were 40, 80, 160 and 240 pounds P_2O_5 per acre. A basal dressing of potassium at the rate of 200 pounds of K_2O per acre was also given.

The soil required for filling three cans was mixed with the

Table 1.--Chemical character of the soils.

Soil	pH	Cation exchange capacity me./100g.	Exchangeable K Lbs./Acre	Available* P Lbs./Acre
Hartsells loam	4.6	8.0	157	40
Dewey silt loam	4.7	8.0	157	68
Grenada silt loam	4.9	8.8	201	34

* Extracted by Bray's reagent, 0.1NHCl + 0.03N NH_4F

fertilizer materials at the specified rates in a twin-shell blender and then divided equally among the triplicate cans. Each can held 3.2 kg. of oven-dry soil. All the 144 cans were filled with the treated soils on April 23, 1960.

About 25-30 sorghum seeds (DeKalb hybrid E-56A) were planted in each can on May 21, 1960. On the day of seeding nitrogen was applied at the rate of 60 lbs. of N per acre in the form of ammonium nitrate solution and the soil moisture was brought to field capacity (approximately 20 percent moisture). About ten days after germination, the plants were thinned to a uniform stand of 15 plants per can. The cans were watered daily with demineralized water so as to bring the moisture to field capacity and the nitrogen was applied at two week intervals at the rate of 60 pounds of N per acre. The first crop was harvested seven weeks after seeding on July 9, and consisted of the above-ground plant material only. The harvested plants from each can were put into a separate paper bag, dried in an air oven at 70° C and the weight recorded. The dried plant material was ground in a Wiley mill and stored in glass bottles for chemical analysis.

After harvesting the first crop, the upper 4 inches of soil in each pot was loosened with the help of a sharp iron rod and the crowns and large roots were removed. On July 13, sorghum was again seeded in all the cans as in the previous case and the plants grown as before. The second crop was also harvested seven weeks after seeding and the yield data recorded on the oven-dry basis. The dried material was ground and stored for chemical analysis.

After the second crop was harvested soil samples were removed from each can for pH and available phosphorus determination. Soils from the triplicate cans were mixed together and the determinations were made on the composite samples.

B. Laboratory Studies

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

1. Soil Studies

Soil studies were planned to observe the changes in pH and available phosphorus occurring in the soils for each of the treatments in the greenhouse experiment. For this, soils treated in the same manner as in the greenhouse experiment except for the replications were taken in cans and kept moist with demineralized water. This involved the use of 48 (4 x 4 x 3 x 1) cans. These cans were also kept in the greenhouse and soil samples were taken from them at intervals of two weeks, except the last sample which was taken four weeks after the previous sampling. The pH and available phosphorus were determined in these samples. The pH was observed by three methods. In one case a soil-water suspension (1:2) was used. In another method the soil was leached with water and the pH noted in an aqueous suspension (1:2) and in the third method M/100 $CaCl_2$ solution was used instead of water as suggested by Schofield and Taylor (30).

Available phosphorus was determined by the method described by Bray and Kurtz (11) with this difference, that 5 g. of the soil

was shaken with 35 ml. of the extractant (0·1N HCl + 0·03N NH_4F) for five minutes and then filtered. The molybdenum blue color was developed in the extract by the 1, 2, 4 amino naphthol sulphonic acid reagent method as suggested by Arnold and Kurtz (3) and the absorbance read in a Fischer photoelectric colorimeter using the 650 mμ. filter.

2. Plant Analysis

The plant material from each can was analysed for its content of P, K, Ca, and Mg using the method suggested by Shaw (31). In broad outline the procedure consisted in digesting a known weight of the ground plant tissue (usually 1.0 g. and 0.5 g. when the yield was less) with a 1:1 mixture of perchloric and nitric acids and making up the solution to a known volume after filtering off the silica. In an aliquot of this solution, phosphorus was determined in the same manner as in the soil extracts. The rest of the solution was evaporated to dryness on a hot plate, the excess perchloric acid removed by heating in a muffle furnace at 200° C and the residue taken up with dilute HCl. Potassium, Ca, and Mg were determined using a Beckman Model DU Flame Spectrophotometer, after precipitating the sulfate with $BaCl_2$, phosphate with $FeCl_3$, and excess $FeCl_3$ and $AlCl_3$ with NH_4OH. The solution was buffered to pH 4.0 with ammonium acetate, filtered, and made up to a known volume before comparing with standards in the flame photometer. The wave lengths used were 767.0 mμ. for K, 422.7 mμ. for Ca and 285.2 mμ. for Mg.

CHAPTER IV

RESULTS

A. Yield

The average yields of oven-dry sorghum per can for the various treatments of the three soils are presented in Tables 2 to 4.

Considerable differences exist among the three soils in their response to lime application. The highest total yield in Hartsells loam was obtained for a liming rate of 2 tons of dolomite per acre, while for higher rates of application the yields were significantly reduced. In Dewey and Grenada silt loams, on the other hand, the yields increased with increasing rates of lime application up to 6 tons of dolomite per acre.

Almost invariably a positive correlation was obtained between the total yield and the rate of phosphorus fertilization in all the three soils.

In the Hartsells loam the second crop was better than the first for almost all the limed treatments, while in the Dewey and Grenada silt loams the second crop was relatively poorer.

Grenada silt loam produced the best total yields when compared to Hartsells and Dewey, but the residual effects as indicated by the yields of the second crop were more pronounced on Hartsells than on the other two soils.

Table 2.--Average yield of oven-dry sorghum on Hartsells loam for different lime and phosphorus treatments.

Treatment		Yield		
Lime tons/acre	P_2O_5 Lbs./acre	First crop g./can	Second crop g./can	Total g./can
0	40	1.51	0.73	2.24
	80	2.22	0.86	3.08
	160	2.43	0.96	3.39
	240	2.18	1.08	3.26
	Mean	2.08	0.91	2.99
2	40	5.99	8.14	14.13
	80	9.17	9.69	18.86
	160	11.15	10.61	21.76
	240	12.69	10.34	23.03
	Mean	9.75	9.69	19.44
4	40	4.16	8.26	12.42
	80	7.58	10.50	18.08
	160	7.00	10.61	17.61
	240	11.46	11.41	22.87
	Mean	7.54	10.20	17.74
6	40	3.33	6.58	9.91
	80	5.22	9.78	15.00
	160	8.18	10.76	18.94
	240	9.67	11.50	21.17
	Mean	6.60	9.66	16.26
All levels	40	3.75	5.93	9.68
	80	6.05	7.71	13.76
	160	7.19	8.24	15.43
	240	9.00	8.58	17.58
L.S.D. Lime and phosphorus means.				
	95 percent level	0.61	0.53	
	99 percent level	0.83	0.72	
Lime x phosphorus				
	95 percent level	1.23	1.06	
	99 percent level	1.65	1.43	

Table 3.--Average yield of oven-dry sorghum on Dewey silt loam for different lime and phosphorus treatments.

Treatment		Yield		
Lime tons/acre	P_2O_5 Lbs./acre	First crop g./can	Second crop g./can	Total g./can
0	40	2.11	0.91	3.02
	80	2.05	1.03	3.08
	160	3.29	0.85	4.14
	240	5.22	0.74	5.96
	Mean	3.17	0.88	4.05
2	40	11.76	5.75	17.51
	80	12.67	5.23	17.90
	160	14.80	4.36	19.16
	240	17.15	4.21	21.36
	Mean	14.09	4.89	18.98
4	40	12.80	4.97	17.77
	80	12.73	6.15	18.88
	160	14.92	5.88	20.80
	240	16.94	5.70	22.64
	Mean	14.35	5.67	20.02
6	40	10.94	6.80	17.74
	80	12.69	8.06	20.75
	160	15.56	5.84	21.40
	240	17.25	7.25	24.50
	Mean	14.11	6.99	21.10
All levels	40	9.40	4.61	14.01
	80	10.03	5.12	15.15
	160	12.14	4.23	16.37
	240	14.14	4.48	18.62
L.S.D. Lime and phosphorus means				
	95 percent level	1.06	0.94	
	99 percent level	1.43	1.27	
Lime x phosphorus				
	95 percent level	2.10	1.90	
	99 percent level	2.83	2.56	

Table 4.--Average yield of oven-dry sorghum on Grenada silt loam for different lime and phosphorus treatments.

Treatment		Yield		
Lime tons/acre	P_2O_5 Lbs./acre	First crop g./can	Second crop g./can	Total g./can
0	40	3.50	2.36	5.86
	80	5.19	4.32	9.51
	160	8.15	5.59	13.74
	240	10.38	5.04	15.42
	Mean	6.80	4.33	11.13
2	40	10.60	4.23	14.83
	80	12.31	5.05	17.36
	160	15.19	5.31	20.50
	240	17.05	5.15	22.20
	Mean	13.79	4.93	18.72
4	40	8.08	9.00	17.08
	80	11.70	7.36	19.06
	160	15.76	7.32	23.08
	240	17.28	8.77	26.05
	Mean	13.21	8.11	21.32
6	40	8.64	9.32	17.96
	80	11.10	10.43	21.53
	160	16.00	10.91	26.91
	240	18.73	11.33	30.06
	Mean	13.62	10.50	24.12
All levels	40	7.70	6.25	13.95
	80	10.08	6.79	16.87
	160	13.78	7.28	21.06
	240	15.86	7.57	23.43
L.S.D. Lime and phosphorus means				
95 percent level		0.70	0.74	
99 percent level		0.94	0.99	
Lime x phosphorus				
95 percent level		1.39	1.48	
99 percent level		1.87	2.01	

B. The Mineral Composition of the Plants

Data showing the mineral composition of the plants for the various treatments of the three soils and for the two crops are given in Tables 5 to 10. The percentage of the applied phosphorus that was taken up by the plants has also been calculated for each treatment and crop on these soils and the results are presented in Tables 11 to 13. The important findings for each nutrient element are as follows:

1. Phosphorus

The percentage of phosphorus in the plants showed a wide variation, ranging from 0.05 to as high as 0.24, the maximum being nearly 5 times the minimum. With the exception of a few cases the phosphorus content of the plants increased with the increase of phosphorus application.

In Hartsells and Dewey soils the highest phosphorus content was obtained for a lime application of 2 tons per acre. But in Grenada silt loam the level of phosphorus in the plants was higher in the unlimed than in the limed soils. However, when the total uptake of phosphorus per can was considered, more phosphorus was removed from the limed samples than from the unlimed samples, although higher rates of lime application generally had a depressing effect upon phosphorus absorption.

The phosphorus content of the plants also showed some differences between the two crops. With the exception of the unlimed Grenada soil the phosphorus content of the plants was generally higher during the second crop than during the first. Total uptake of phosphorus was

Table 5.--Mineral composition of sorghum grown on Hartsells loam for different lime and phosphorus treatments.
(First crop)

Treatment		Composition of plant material (oven-dry basis)			
Lime tons/acre	P_2O_5 Lbs./acre	P %	K %	Ca %	Mg %
0	40	0.05	1.27	1.05	0.22
	80	0.06	1.13	1.05	0.20
	160	0.06	1.35	1.08	0.22
	240	0.06	1.28	1.11	0.22
	Mean	0.06	1.26	1.07	0.22
2	40	0.11	2.64	0.83	0.59
	80	0.13	2.73	0.73	0.58
	160	0.16	2.45	0.74	0.71
	240	0.17	2.08	0.76	0.76
	Mean	0.14	2.48	0.76	0.66
4	40	0.10	2.10	0.79	0.57
	80	0.13	1.90	0.82	0.60
	160	0.13	2.30	0.77	0.54
	240	0.16	2.03	0.74	0.62
	Mean	0.13	2.08	0.78	0.58
6	40	0.08	1.68	0.91	0.50
	80	0.12	2.23	0.86	0.53
	160	0.13	1.91	0.78	0.59
	240	0.14	2.08	0.77	0.64
	Mean	0.12	1.98	0.83	0.56
All levels	40	0.09	1.92	0.90	0.47
	80	0.11	2.00	0.86	0.48
	160	0.12	2.00	0.84	0.52
	240	0.13	1.87	0.84	0.56
L.S.D. Lime and phosphorus means					
95 percent level		0.01	0.14	0.04	0.02
99 percent level		0.01	0.19	0.06	0.03
Lime x phosphorus					
95 percent level		0.02	0.28	0.08	0.04
99 percent level		0.02	0.38	0.12	0.06

Table 6.--Mineral composition of sorghum grown on Dewey silt loam for different lime and phosphorus treatments.
(First Crop)

Treatment		Composition of plant material (oven-dry basis)			
Lime tons/acre	P_2O_5 Lbs./acre	P %	K %	Ca %	Mg %
0	40	0.06	1.60	0.71	0.19
	80	0.05	1.46	0.76	0.20
	160	0.09	1.74	0.73	0.19
	240	0.17	2.14	0.78	0.22
	Mean	0.09	1.74	0.74	0.20
2	40	0.17	2.71	0.56	0.70
	80	0.19	2.70	0.57	0.78
	160	0.24	2.46	0.57	0.79
	240	0.23	2.09	0.64	0.80
	Mean	0.21	2.49	0.58	0.77
4	40	0.16	2.61	0.58	0.82
	80	0.18	2.56	0.56	0.86
	160	0.21	2.33	0.54	0.88
	240	0.20	2.04	0.61	0.98
	Mean	0.19	2.36	0.57	0.88
6	40	0.16	2.76	0.57	0.76
	80	0.16	2.68	0.55	0.71
	160	0.17	2.14	0.58	0.78
	240	0.17	1.87	0.56	0.75
	Mean	0.16	2.39	0.56	0.75
All levels	40	0.14	2.42	0.60	0.62
	80	0.15	2.35	0.61	0.65
	160	0.18	2.17	0.60	0.66
	240	0.19	2.04	0.65	0.69
L.S.D. Lime and phosphorus means					
95 percent level		0.01	0.12	0.03	0.03
99 percent level		0.02	0.16	0.04	0.04
Lime x phosphorus					
95 percent level		0.03	0.24	0.06	0.06
99 percent level		0.04	0.32	0.08	0.08

Table 7.--Mineral composition of sorghum grown on Grenada silt loam for different lime and phosphorus treatments.
(First Crop)

Treatment		Composition of plant material (oven-dry basis)			
Lime tons/acre	P_2O_5 Lbs./acre	P %	K %	Ca %	Mg %
0	40	0.12	1.72	0.70	0.48
	80	0.18	1.98	0.66	0.50
	160	0.21	2.12	0.63	0.46
	240	0.21	2.17	0.58	0.50
	Mean	0.18	2.00	0.64	0.48
2	40	0.11	2.53	0.61	0.50
	80	0.14	2.26	0.68	0.64
	160	0.15	1.89	0.66	0.70
	240	0.16	1.83	0.67	0.74
	Mean	0.14	2.13	0.66	0.64
4	40	0.14	2.73	0.77	0.42
	80	0.13	2.56	0.80	0.48
	160	0.14	2.18	0.73	0.49
	240	0.14	2.08	0.82	0.52
	Mean	0.14	2.39	0.78	0.48
6	40	0.14	2.27	0.82	0.46
	80	0.13	2.15	0.84	0.44
	160	0.13	2.18	0.82	0.50
	240	0.12	1.97	0.76	0.43
	Mean	0.13	2.14	0.81	0.46
All levels	40	0.13	2.31	0.72	0.46
	80	0.14	2.24	0.74	0.52
	160	0.16	2.09	0.71	0.54
	240	0.16	2.01	0.71	0.55
L.S.D. Lime and phosphorus means					
95 percent level		0.01	0.05	0.04	0.03
99 percent level		0.01	0.07	0.05	0.04
Lime x phosphorus					
95 percent level		0.02	0.11	0.07	0.06
99 percent level		0.03	0.14	0.10	0.08

Table 8.--Mineral composition of sorghum grown on Hartsells loam for different lime and phosphorus treatments.
(Second crop)

Treatment		Composition of plant material (oven-dry basis)			
Lime tons/acre	P_2O_5 Lbs./acre	P %	K %	Ca %	Mg %
0	40	0.10	1.49	1.44	0.25
	80	0.13	1.44	1.54	0.24
	160	0.09	1.41	1.59	0.24
	240	0.14	1.93	1.74	0.24
	Mean	0.12	1.57	1.58	0.24
2	40	0.08	1.95	0.89	0.52
	80	0.11	1.35	0.87	0.80
	160	0.15	1.16	0.97	0.93
	240	0.19	0.97	1.04	0.97
	Mean	0.13	1.36	0.94	0.80
4	40	0.09	2.64	0.94	0.73
	80	0.11	1.62	0.84	1.09
	160	0.16	1.77	0.87	1.09
	240	0.19	0.98	0.93	1.24
	Mean	0.14	1.75	0.90	1.04
6	40	0.10	2.94	0.94	0.68
	80	0.12	1.98	0.90	1.03
	160	0.16	1.35	0.92	1.12
	240	0.18	1.02	0.91	1.14
	Mean	0.14	1.82	0.92	1.00
All levels	40	0.09	2.26	1.05	0.54
	80	0.12	1.60	1.04	0.79
	160	0.14	1.42	1.09	0.84
	240	0.17	1.22	1.15	0.90
L.S.D. Lime and phosphorus means					
95 percent level		0.01	0.14	0.10	0.04
99 percent level		0.02	0.19	0.13	0.05
Lime x phosphorus					
95 percent level		0.03	0.28	0.19	0.08
99 percent level		0.04	0.37	0.26	0.10

Table 9.--Mineral composition of sorghum grown on Dewey silt loam for different lime and phosphorus treatments.
(Second crop)

Treatment		Composition of plant material (oven-dry basis)			
Lime tons/acre	P_2O_5 Lbs./acre	P %	K %	Ca %	Mg %
0	40	0.11	1.88	0.90	0.18
	80	0.09	1.73	0.92	0.16
	160	0.14	2.11	1.03	0.19
	240	0.16	1.66	1.13	0.18
	Mean	0.13	1.84	1.00	0.18
2	40	0.17	1.23	1.11	0.99
	80	0.22	1.17	1.14	0.94
	160	0.24	1.24	1.16	0.84
	240	0.24	1.13	1.24	0.77
	Mean	0.22	1.19	1.16	0.88
4	40	0.17	1.34	1.19	1.09
	80	0.18	1.13	1.20	1.11
	160	0.19	1.04	1.21	1.13
	240	0.19	0.88	1.21	1.13
	Mean	0.18	1.10	1.20	1.12
6	40	0.21	1.27	1.18	1.23
	80	0.16	0.94	1.16	1.27
	160	0.22	0.91	1.26	1.34
	240	0.22	0.83	1.19	1.37
	Mean	0.20	0.99	1.20	1.30
All levels	40	0.16	1.43	1.10	0.87
	80	0.16	1.24	1.10	0.87
	160	0.20	1.32	1.16	0.88
	240	0.20	1.12	1.19	0.86
L.S.D. Lime and phosphorus means					
95 percent level		0.02	0.10	0.06	0.03
99 percent level		0.02	0.14	0.08	0.04
Lime x phosphorus					
95 percent level		0.04	0.21	0.12	0.07
99 percent level		0.05	0.28	0.16	0.09

Table 10.--Mineral composition of sorghum grown on Grenada silt loam for different lime and phosphorus treatments.
(Second crop)

Treatment		Composition of plant material (oven-dry basis)			
Lime tons/acre	P_2O_5 Lbs./acre	P %	K %	Ca %	Mg %
0	40	0.10	1.45	0.72	0.50
	80	0.14	2.07	0.68	0.48
	160	0.19	1.79	0.74	0.75
	240	0.18	1.35	0.66	0.69
	Mean	0.15	1.66	0.70	0.60
2	40	0.14	1.92	1.01	0.91
	80	0.14	1.56	0.94	0.91
	160	0.18	1.17	0.90	1.03
	240	0.21	1.11	0.94	1.09
	Mean	0.17	1.44	0.95	0.98
4	40	0.12	1.22	0.94	0.84
	80	0.12	1.24	1.11	0.96
	160	0.15	1.07	1.12	1.15
	240	0.17	0.92	1.11	1.12
	Mean	0.14	1.11	1.07	1.02
6	40	0.14	1.36	1.05	0.85
	80	0.14	1.15	1.09	0.99
	160	0.14	0.84	1.03	1.06
	240	0.17	0.78	1.00	1.19
	Mean	0.15	1.04	1.04	1.02
All levels	40	0.13	1.49	0.93	0.78
	80	0.13	1.50	0.96	0.84
	160	0.16	1.22	0.95	1.00
	240	0.18	1.04	0.93	1.02
L.S.D. Lime and phoshporus means					
95 percent level		0.01	0.09	0.22	0.08
99 percent level		0.02	0.12	0.29	0.11
Lime x phosphorus					
95 percent level		0.03	0.18	0.43	0.16
99 percent level		0.04	0.24	0.58	0.22

Table 11.--Phosphorus recovery by sorghum from Hartsells loam at different rates of lime and phosphorus application.

Treatment		P Applied	Phosphorus recovery					
			First	Second		First	Second	
Lime tons/acre	P_2O_5 Lbs./acre	per can mg.	crop mg./can	crop mg./can	Total mg./can	crop %	crop %	Total %
0	40	31.7	0.76	0.73	1.49	2.39	2.30	4.69
	80	63.3	1.31	1.13	2.44	2.07	1.78	3.85
	160	126.7	1.36	0.89	2.25	1.07	0.70	1.77
	240	190.0	1.26	1.46	2.72	0.66	0.77	1.43
2	40	31.7	6.59	6.84	13.43	20.79	21.58	42.37
	80	63.3	11.73	10.37	22.10	18.53	16.38	34.91
	160	126.7	18.40	15.70	34.10	14.52	12.39	26.91
	240	190.0	21.70	19.23	40.93	11.42	10.12	21.54
4	40	31.7	4.16	7.52	11.68	13.12	23.72	36.84
	80	63.3	9.70	11.66	21.36	15.32	18.42	33.74
	160	126.7	9.24	16.98	26.22	7.29	13.40	20.69
	240	190.0	18.79	21.22	40.01	9.89	11.17	21.06
6	40	31.7	2.83	6.45	9.38	8.93	20.35	29.58
	80	63.3	6.06	11.54	17.60	9.57	18.23	27.80
	160	126.7	10.39	17.11	27.50	8.20	13.50	21.70
	240	190.0	13.15	20.59	33.74	6.92	10.84	17.76

Table 12.--Phosphorus recovery by sorghum from Dewey silt loam at different rates of lime and phosphorus application.

Treatment		P Applied	Phosphorus recovery					
			First crop	Second crop		First crop	Second crop	
Lime tons/acre	P_2O_5 Lbs./acre	per can mg.	mg./can	mg./can	Total mg./can	%	%	Total %
0	40	31.7	1.31	0.99	2.30	4.13	3.12	7.25
	80	63.3	1.09	0.96	2.05	1.72	1.52	3.24
	160	126.7	3.06	1.22	4.28	2.42	0.96	3.38
	240	190.0	8.77	1.21	9.98	4.61	0.64	5.25
2	40	31.7	20.34	9.83	30.17	64.16	31.00	95.16
	80	63.3	24.58	11.40	35.98	38.83	18.00	56.83
	160	126.7	34.93	10.64	45.57	27.57	8.40	35.97
	240	190.0	38.76	10.27	49.03	20.40	5.41	25.81
4	40	31.7	20.48	8.25	28.73	64.60	26.03	90.63
	80	63.3	23.30	10.58	33.88	36.81	16.71	53.52
	160	126.7	30.88	11.17	42.05	24.37	8.82	33.19
	240	190.0	33.54	10.89	44.63	17.65	5.73	23.38
6	40	31.7	17.29	14.48	31.77	54.54	45.68	100.22
	80	63.3	20.05	13.22	33.27	31.67	20.88	52.55
	160	126.7	26.92	12.84	39.76	21.25	10.13	31.38
	240	190.0	28.81	15.73	44.54	15.16	8.28	23.44

Table 13.--Phosphorus recovery by sorghum from Grenada silt loam at different rates of lime and phosphorus application.

Treatment		P Applied	Phosphorus recovery					
			First	Second		First	Second	
Lime	P_2O_5	per can	crop	crop	Total	crop	crop	Total
tons/acre	Lbs./acre	mg.	mg./can	mg./can	mg./can	%	%	%
0	40	31.7	4.31	2.38	6.69	13.60	7.51	21.11
	80	63.3	9.13	5.92	15.05	14.42	9.35	23.77
	160	126.7	16.95	10.57	27.52	13.38	8.34	21.72
	240	190.0	21.90	9.32	31.22	11.53	4.91	16.44
2	40	31.7	11.55	6.13	17.68	36.44	19.34	55.78
	80	63.3	16.86	6.82	23.68	26.64	10.77	37.41
	160	126.7	23.39	9.61	33.00	18.46	7.58	26.04
	240	190.0	27.45	10.61	38.06	14.45	5.58	20.03
4	40	31.7	11.07	10.71	21.78	34.92	33.79	68.71
	80	63.3	15.33	8.66	23.99	24.22	13.68	37.90
	160	121.7	21.91	10.76	32.67	17.29	8.49	25.78
	240	190.0	23.67	15.00	38.67	12.46	7.89	20.35
6	40	31.7	11.83	12.77	24.60	37.32	40.28	77.60
	80	63.3	14.32	14.92	29.24	22.62	23.57	46.19
	160	126.7	21.12	14.95	36.07	16.67	11.80	28.47
	240	190.0	23.23	19.49	42.72	12.23	10.26	22.49

however, lower during the second crop in Dewey and Grenada, due to the lower yields.

The increased phosphorus content during the second crop was co-existent with a corresponding tendency for increased levels of magnesium, and an increase in the available phosphorus after the sixth week as revealed by laboratory studies.

2. Potassium

Potassium showed less variation than phosphorus in the plants, ranging from 0.78% to 2.94%, the maximum being about 3.7 times the minimum. The level of potassium in the plants grown on the unlimed Hartsells and Dewey during the first crop was significantly lower than that in the plants grown on the limed soils. These two soils exhibited symptoms of magnesium deficiency in the form of albinism on the unlimed treatments and the complex nature of the interactions between the different cations occurring under such conditions probably accounts for this phenomenon.

Differences were noted between the potassium contents of the plants grown in the two crops. The second crop generally contained a lower level of potassium than the first, which might be due to a diminished supply of this element in the soil as a result of the removal by the first crop. A higher level of calcium and magnesium in the plants during the second crop might also have been responsible for a correspondingly lowered uptake of potassium.

The reciprocal potassium-phosphorus relationship reported by some workers was also verified by, and discernible in the data obtained.

3. Calcium

Among the nutrient elements studied calcium appeared to be the least variable in the plants. In spite of the widely varying rates of lime applied to the soil, the level of calcium in the plants ranged only between 0.54% and 1.74%, the maximum being about 3.2 times the minimum. These results would indicate that the calcium content of the plants was not necessarily dependent upon the level of calcium in the soil and that there were factors other than the total supply which influenced its absorption by plants. The level of calcium in the plants grown on the unlimed Hartsells and Dewey was even higher than that in the plants grown on the limed soils during the first crop. This tendency persisted in Hartsells during the second crop also, and appeared to be because a deficiency of magnesium in these soils was to some extent compensated for by an increased absorption of calcium. This tendency disappeared in the Dewey soil during the second crop, and may have resulted from the fact that the plants grown on these unlimed soils during the second crop contained a higher level of potassium. The Ca:K ratio in these soils might have been significantly reduced by the removal of Ca by the first crop.

4. Magnesium

Magnesium was the most variable of the elements considered, varying between 0.16 and 1.37 percent. The maximum percentage in this case was nearly 8.5 times the minimum. A deficiency of this element in the crop growing in two of the unlimed soils has apparently contributed towards

this higher ratio. A positive correlation existed between the levels of magnesium and those of phosphorus in the plants, which may be explained by assuming that magnesium functions as a carrier for phosphorus.

The concentration of magnesium in the plants increased during the second crop as compared with the first crop. This might have occurred for one or more of several reasons. Firstly the concentration of magnesium in the soil solution might have increased during the period of the second crop by the increased dissolution of Mg from the dolomite. Secondly, an increase in the Mg:K ratio might have resulted during the second crop consequent on the removal of potassium from the available supply by the first crop. Thirdly, an increased availability of phosphorus during the second crop might have resulted in an increased absorption of magnesium.

The inverse Ca-Mg relationship reported in literature was also observed in the results presented.

C. Cation Equivalence in Sorghum

The cation content of the plants, expressed as milliequivalents per 100 g. of plant material is presented in Tables 14 to 16. The total number of milliequivalents of cations per 100 g. of plant material has in all cases been less in the unlimed than in the limed soils. The total cation concentration was greater for the second crop, which might be attributed to an increased concentration of Ca and Mg in the soil solution because of continuing dissolution of dolomite and to a reduced vegetative growth due to the operation of some other limiting factor.

Table 14.--Cation content of sorghum grown on Hartsells loam for different treatments of lime and phosphorus.

Treatment		First crop				Second crop			
Lime tons/acre	P_2O_5 Lbs./acre	K	Ca	Mg	Total cations	K	Ca	Mg	Total cations
		me./100g.							
0	40	32.6	52.4	18.5	103.5	38.2	72.2	21.0	131.4
	80	34.2	52.4	17.0	103.6	36.8	77.0	20.3	134.1
	160	34.6	54.1	17.9	106.6	36.2	79.4	20.3	135.9
	240	32.8	55.6	18.6	106.0	49.5	87.2	20.0	156.7
2	40	67.8	41.5	48.9	158.2	49.9	44.4	43.5	137.8
	80	70.1	36.7	48.2	155.0	34.5	43.7	66.6	144.8
	160	62.8	37.2	59.3	147.7	29.8	48.7	77.7	156.2
	240	53.4	38.2	63.6	155.2	24.9	52.2	80.8	157.9
4	40	53.9	39.6	47.3	140.8	67.7	46.8	61.0	175.5
	80	48.7	40.6	49.1	138.4	41.4	42.2	90.7	174.3
	160	58.9	38.7	45.0	142.6	45.4	43.3	90.9	179.6
	240	52.0	37.2	51.5	140.7	25.1	46.7	103.6	175.4
6	40	43.0	45.4	41.7	130.1	75.5	46.8	56.4	178.7
	80	57.3	43.2	44.4	144.9	50.8	45.0	86.0	181.8
	160	49.0	37.5	48.6	135.1	34.5	46.3	93.8	174.6
	240	53.3	37.8	52.3	143.4	26.2	45.5	94.9	166.6

Table 15.--Cation content of sorghum grown on Dewey silt loam for different treatments of lime and phosphorus.

Treatment		First crop				Second crop			
Lime tons/acre	P_2O_5 Lbs./acre	K	Ca	Mg	Total cations	K	Ca	Mg	Total cations
		me./100g.							
0	40	41.0	35.6	15.8	92.4	48.3	45.0	15.4	108.7
	80	37.4	38.2	16.7	92.3	44.3	46.2	12.9	103.4
	160	44.6	36.3	15.9	96.8	54.1	50.2	15.8	120.1
	240	54.9	39.3	17.9	112.1	42.5	56.6	14.8	113.9
2	40	69.5	27.8	58.3	155.6	31.5	55.4	82.9	169.8
	80	69.3	28.4	64.8	162.5	29.9	56.8	78.7	165.4
	160	63.0	28.5	66.0	157.5	31.7	58.1	70.3	160.1
	240	53.5	31.9	66.3	151.7	29.0	62.2	64.4	155.6
4	40	66.8	28.9	68.5	164.2	34.3	59.7	54.1	148.1
	80	65.5	28.1	71.3	164.9	29.0	59.9	68.1	157.0
	160	59.7	27.2	73.1	160.0	26.6	60.5	66.6	153.7
	240	52.4	30.4	81.5	164.3	22.6	60.6	64.6	148.0
6	40	70.7	28.7	63.3	162.7	32.5	59.0	83.5	175.0
	80	68.7	27.4	59.3	155.4	24.1	58.1	102.3	184.5
	160	55.0	28.4	64.8	148.2	23.4	62.9	78.2	164.5
	240	48.1	27.9	62.7	138.7	21.2	59.4	99.3	179.9

Table 16.--Cation content of sorghum grown on Grenada silt loam for different treatments of lime and phosphorus

Treatment		First crop				Second crop			
Lime tons/acre	P_2O_5 Lbs./acre	K	Ca	Mg	Total cations	K	Ca	Mg	Total cations
		me./100g.							
0	40	44.0	34.8	39.8	118.6	37.2	35.8	41.5	114.5
	80	50.9	32.8	41.3	125.0	53.1	34.2	39.6	126.9
	160	54.3	31.7	38.8	124.8	45.8	37.1	62.2	145.1
	240	55.6	29.1	41.4	126.1	34.7	33.1	57.5	125.3
2	40	64.9	30.6	41.4	136.9	49.2	50.0	75.5	175.2
	80	57.8	34.1	53.1	129.8	40.0	47.1	75.5	162.6
	160	48.4	33.2	58.0	139.6	30.0	45.2	86.1	161.3
	240	46.9	33.7	61.8	142.4	28.6	46.8	90.9	166.3
4	40	70.1	38.4	35.2	143.7	31.3	46.8	70.0	148.1
	80	65.5	40.0	40.2	145.7	31.9	55.5	80.3	167.7
	160	56.0	36.3	41.1	133.4	27.5	55.9	95.6	179.0
	240	53.4	41.1	43.5	138.0	23.6	55.3	93.8	172.7
6	40	58.1	41.1	38.0	137.2	35.0	52.4	70.9	158.3
	80	55.1	41.9	36.8	133.8	29.5	54.6	82.2	166.3
	160	55.8	41.1	41.3	138.2	21.5	51.4	88.3	161.2
	240	50.5	37.8	36.1	124.4	20.0	49.8	99.4	169.2

The average values of cation equivalence for the various treatments during the first crop were 135.5 for Hartsells, 142.5 for Dewey, and 133.6 for Grenada. The corresponding figures for the second crop were 160.1, 150.5, and 156.2 respectively. The average values for the two crops were 147.3 for Hartsells, 146.5 for Dewey and 144.9 for Grenada and this constancy of the cation equivalence of sorghum grown on these different soils was remarkably good.

D. Soil Incubation Studies

The results of the soil incubation studies are presented in Tables 17 to 22. These tables reveal the variation in the pH and available phosphorus in the three soils for the different treatments over a period of twelve weeks. These results may be compared with the data in the Tables 23 to 25 which give the pH and available phosphorus at the end of the experiment in the soils in which the plants were actually grown.

1. Liming and Soil Reaction

The pH values of the soils were influenced almost entirely by the lime treatments and only insignificantly by the different levels of phosphate application. Tables 17 to 19 present the average pH values for the different liming rates determined by three different methods. Leaching of the soil with water raised the pH by about 0.4 - 0.7 units above that of the unleached sample. The pH determined by using M/100 $CaCl_2$, on the other hand, was about 0.1 - 0.3 units below that of the unleached soil in water suspension. Although many advantages have been ascribed to the leaching

Table 17.--Change in pH of Hartsells loam with treatment and time (Incubated soils).

Treatment lime tons/acre	pH on May 2	May 16	May 30	June 13	June 27	July 25
			Before leaching with water			
0	4.7	4.8	4.8	4.8	4.7	4.6
2	5.4	6.1	5.9	5.9	5.6	5.5
4	5.7	6.6	6.7	6.8	6.6	6.3
6	5.9	7.0	7.0	7.2	7.0	6.8
			After leaching with water			
0	5.5	5.5	5.4	5.5	5.3	5.3
2	6.2	6.8	6.5	6.5	6.2	6.2
4	6.5	7.2	7.2	7.5	7.2	7.0
6	6.6	7.4	7.5	7.7	7.4	7.4
			In $\frac{M}{100}$ $CaCl_2$ Solution			
0	4.4	4.5	4.5	4.5	4.3	4.3
2	5.1	5.8	5.8	5.7	5.5	5.2
4	5.5	6.3	6.4	6.7	6.5	6.1
6	5.7	6.6	6.7	6.9	6.7	6.6

Table 18.--Change in pH of Dewey silt loam with treatment and time (Incubated soils).

Treatment lime tons/acre	pH on May 2	May 16	May 30	June 13	June 27	July 25
			Before leaching with water			
0	4.5	4.7	4.7	4.7	4.7	4.6
2	5.2	6.0	6.0	5.8	5.7	5.5
4	5.5	6.4	6.6	6.5	6.6	6.4
6	5.8	6.6	6.7	6.8	6.8	6.7
			After leaching with water			
0	5.2	5.1	5.2	5.2	5.1	5.2
2	6.2	6.7	6.3	6.4	6.2	6.1
4	6.9	7.0	7.1	7.3	7.3	7.0
6	7.0	7.1	7.2	7.5	7.5	7.5
			In $\frac{M}{100}$ $CaCl_2$ Solution			
0	4.4	4.3	4.3	4.4	4.4	4.4
2	5.1	5.8	5.6	5.5	5.5	5.2
4	5.3	6.2	6.4	6.4	6.5	6.3
6	5.5	6.5	6.6	6.7	6.7	6.6

Table 19.--Change in pH of Grenada silt loam with treatment and time (Incubated soils).

Treatment lime tons/acre	pH on May 2	May 16	May 30	June 13	June 27	July 25
	Before leaching with water					
0	4.8	4.7	4.7	4.6	4.5	4.4
2	5.3	6.0	6.0	5.9	5.8	5.7
4	5.7	6.6	6.7	6.6	6.6	6.7
6	5.9	6.8	6.9	7.0	7.0	7.1
	After leaching with water					
0	5.4	5.1	5.2	5.2	5.1	5.0
2	6.3	6.6	6.4	6.5	6.5	6.2
4	6.9	7.1	7.3	7.4	7.3	7.1
6	7.1	7.4	7.5	7.7	7.7	7.5
	In $\frac{M}{100}$ $CaCl_2$ Solution					
0	4.4	4.4	4.3	4.3	4.4	4.2
2	5.0	5.9	5.7	5.7	5.7	5.5
4	5.5	6.5	6.4	6.5	6.5	6.4
6	5.6	6.6	6.7	6.8	6.8	6.8

Table 20.--Change in available phosphorus in Hartsells loam with treatment and time (Incubated soils).

Treatment		Available P (pounds per acre) on						Average
Lime tons/acre	P_2O_5 Lbs./acre	May 2	May 16	May 30	June 13	June 27	July 25	for the period
0	40	203	157	146	91	90	122	137
	80	193	125	150	85	109	153	136
	160	197	158	169	105	110	144	147
	240	169	179	171	120	119	183	157
2	40	195	155	151	102	106	140	142
	80	188	162	168	106	105	129	143
	160	181	151	133	98	125	150	156
	240	190	160	174	119	120	175	156
4	40	210	172	127	108	116	137	145
	80	217	165	164	112	109	147	152
	160	202	169	143	112	123	176	154
	240	213	190	160	134	126	181	167
6	40	242	132	164	104	106	148	149
	80	221	167	143	105	102	159	150
	160	209	154	171	116	113	164	155
	240	228	154	164	132	129	188	166

Table 21.--Change in available phosphorus in Dewey silt loam with treatment and time (Incubated soils).

Treatment		Available P (Pounds per acre) on						Average
Lime tons/acre	P_2O_5 Lbs./acre	May 2	May 16	May 30	June 13	June 27	July 25	for the period
0	40	192	175	140	139	129	200	163
	80	202	158	139	146	129	186	160
	160	192	172	164	164	143	228	177
	240	203	217	164	176	178	244	197
2	40	175	134	151	148	123	189	153
	80	192	188	153	148	132	195	153
	160	179	157	153	168	143	209	168
	240	183	195	175	179	171	234	190
4	40	163	118	120	121	116	204	140
	80	163	85	92	123	141	204	135
	160	160	129	101	132	143	209	146
	240	133	132	78	146	148	223	143
6	40	200	151	83	126	127	211	150
	80	133	113	97	123	126	217	135
	160	185	151	94	143	150	220	157
	240	178	155	112	149	162	255	169

Table 22.--Change in available phosphorus in Grenada silt loam with treatment and time (Incubated soils).

Treatment		Available P (pounds per acre) on						Average
Lime tons/acre	P_2O_5 Lbs./acre	May 2	May 16	May 30	June 13	June 27	July 25	for the period
0	40	137	87	60	111	138	118	109
	80	99	98	67	126	116	115	104
	160	153	109	70	132	127	123	119
	240	143	106	63	134	160	146	125
2	40	193	102	79	148	157	136	136
	80	178	104	83	119	153	123	127
	160	174	109	79	132	141	137	129
	240	193	113	97	143	159	153	143
4	40	129	105	81	148	137	129	122
	80	109	115	111	134	169	148	131
	160	206	98	76	85	159	138	127
	240	182	129	103	167	183	157	154
6	40	143	119	57	148	179	159	134
	80	148	109	59	163	170	137	131
	160	169	104	98	176	185	153	148
	240	182	122	98	167	169	165	151

Table 23.--Soil reaction and available phosphorus in Hartsells loam after the second harvest. (Composite Soils)

Treatment		pH			Available P
Lime tons/acre	P_2O_5 Lbs./acre	A	B	C	Lbs./acre
0	40	4.3	5.1	4.2	48
	80	4.3	5.1	4.2	52
	160	4.3	5.1	4.2	67
	240	4.1	5.0	4.1	83
2	40	5.5	6.2	5.3	38
	80	5.6	6.3	5.4	41
	160	5.7	6.3	5.5	49
	240	5.8	6.4	5.5	56
4	40	6.2	6.9	6.0	43
	80	6.4	7.0	6.1	41
	160	6.4	7.0	6.1	60
	240	6.5	7.1	6.3	62
6	40	6.8	7.4	6.7	42
	80	6.8	7.4	6.6	48
	160	6.8	7.4	6.6	46
	240	7.0	7.4	6.7	64

A = before leaching with water
B = after leaching with water
C = in $\frac{M}{100}$ $CaCl_2$ solution

Table 24.--Soil reaction and available phosphorus in Dewey silt loam after the second harvest (Composite soils).

Treatment		pH			Available P
Lime tons/acre	P_2O_5 Lbs./acre	A	B	C	Lbs./acre
0	40	4.2	4.8	4.2	69
	80	4.2	4.9	4.2	76
	160	4.2	4.9	4.2	91
	240	4.2	4.8	4.2	113
2	40	5.6	6.1	5.4	69
	80	5.5	6.1	5.4	64
	160	5.3	5.9	5.1	83
	240	5.5	6.1	5.1	93
4	40	6.4	6.9	6.3	59
	80	6.3	6.9	6.1	74
	160	6.4	7.0	6.1	80
	240	6.5	7.0	6.3	85
6	40	6.9	7.5	6.6	69
	80	6.9	7.4	6.8	69
	160	7.0	7.5	6.7	80
	240	7.0	7.5	6.8	90

A = before leaching with water
B = after leaching with water
C = in $\frac{M}{100}$ $CaCl_2$ solution

Table 25.--Soil reaction and available phosphorus in Grenada silt loam after the second harvest (Composite soils).

Treatment					Available
Lime	P_2O_5	pH			P
tons/acre	Lbs./acre	A	B	C	Lbs./acre
0	40	4.4	4.9	4.1	46
	80	4.5	5.0	4.1	41
	160	4.4	5.0	4.2	46
	240	4.4	5.0	4.2	60
2	40	5.7	6.1	5.4	38
	80	5.7	6.2	5.4	40
	160	6.0	6.3	5.6	46
	240	5.9	6.3	5.6	53
4	40	6.8	7.1	6.7	39
	80	7.0	7.3	6.7	43
	160	6.9	7.3	6.6	48
	240	7.0	7.3	6.7	57
6	40	7.2	7.6	7.0	46
	80	7.2	7.6	7.0	47
	160	7.3	7.6	7.0	50
	240	7.3	7.6	7.0	60

A = before leaching with water
B = after leaching with water
C = in $\frac{M}{100}$ $CaCl_2$ solution

of the soils and to the using of the $CaCl_2$ medium over that of an aqueous suspension for determining soil pH, for the purpose of this discussion, the pH values obtained in the water suspension alone are considered.

Equal rates of lime application have raised the pH of different soils to different extents. Thus, an application of 2 tons of lime per acre raised the pH of Hartsells loam from 4.6 to a maximum of 6.1, that of Dewey silt loam from 4.7 to 6.0 and of Grenada silt loam from 4.9 to 6.0 during the period of observation. The corresponding values for a liming rate of 4 tons per acre were 6.8, 6.6 and 6.7, and for 6 tons of lime per acre they were 7.2, 6.8 and 7.0 respectively for the three soils. In other words, an application of 2 tons of lime per acre has raised the pH of these soils through a range of 1.5, 1.3 and 1.1 units respectively. The corresponding figures for a liming rate of 4 tons per acre are 2.2, 2.0 and 1.8 and for a rate of 6 tons per acre these values are respectively 2.6, 2.1 and 2.1. These results serve to illustrate the principle that different soils have to be limed to different levels to reach the same reaction.

The final pH values of the soils in which the plants were grown agreed closely with those of the incubated soil samples at the end of the 12 week period. This result would suggest that the growth of the plants did not significantly influence the soil reaction over the period of growth.

2. Availability of Added Phosphorus

Two tendencies were generally discernible in the amounts of phosphorus extracted by Bray's reagent over the period under study:

(1) The amounts of extractable phosphorus increased with increasing rates of lime and phosphorus application;

(2) The extractable phosphorus decreased to a minimum during the period of 4 to 6 weeks and then increased again.

The beneficial effects of lime on the availability of phosphorus may apparently be attributed to its retarding effect on the fixation of added phosphorus as iron and aluminum phosphates. The decrease of extractable phosphorus to a minimum during the period of 4 to 6 weeks corresponds to the period of maximum fixation and the increase of extractable phosphorus thereafter indicates increasing release of organic phosphorus in the available form by microbiological activity.

The three untreated soils, Hartsells, Dewey and Grenada originally contained 40, 68, and 34 pounds per acre of extractable phosphorus respectively. When phosphorus was applied at the rates of 40, 80, 160 and 240 pounds of P_2O_5 per acre the available phosphorus in the Hartsells soil was increased to an average of 143, 145, 153 and 163 pounds of P per acre respectively over the 12 week period. In the Dewey silt loam the corresponding figures were 152, 146, 162 and 175, and in Grenada 125, 123, 131 and 143 pounds of P per acre. In the Hartsells loam the amounts of extractable phosphorus at the end of the experiment in the soils in which the plants were grown were 43, 46, 56 and 66 pounds of P per acre.

In Dewey these values were 66, 71, 84 and 95 pounds of P per acre and in Grenada 42, 43, 48 and 57 pounds of P per acre respectively.

Phosphorus treatments of the different soils increased the available phosphorus in the incubated samples to values in excess of the added phosphorus and this greater availability might be due to the release of some of the organic native phosphorus to the available form by microbiological activity. At the end of the experiment the levels of extractable phosphorus in the cans in which the plants were grown were less than those in the incubated soils. In many instances the levels of extractable phosphorus had dropped to the original values in the untreated soils. This is evidently due to the removal of available phosphorus from the soils in which the plants were grown, although the difference between the amounts of extractable phosphorus in the incubated soils and those in the soils in which the plants grew did not represent the exact amounts removed by them. The reactions taking place in a system such as the incubated soil samples are different from those in a system like the soils in which the plants are grown, and hence the difficulty in applying the results obtained in one to the other.

An application of 40 pounds of P_2O_5 per acre raised the level of available phosphorus in the incubated Dewey soil to 152 pounds of P per acre, while it required a rate of 160 pounds P_2O_5 per acre to bring the amount of available phosphorus in Hartsells to a level of 153 pounds of P per acre. But in Grenada a phosphorus application of

240 pounds of P_2O_5 per acre resulted in an available phosphorus level of only 143 pounds of P per acre. Again, an application of 40 pounds of P_2O_5 per acre to Hartsells and of 240 pounds of P_2O_5 per acre to Grenada resulted in the same level of available phosphorus, viz., 143 pounds of P per acre. Similar trends were discernible in the amounts of available phosphorus in the soils in which the plants were grown.

These results would suggest that the response to phosphorus fertilization in these soils would diminish in the order Dewey, Hartsells and Grenada. Tables 11 to 13 indicate that the highest total amounts of phosphorus were actually removed by sorghum from Dewey, but the next highest amounts were removed from Grenada rather than from Hartsells which was probably due to the operation of some other limiting factor in this soil.

3. Soil Reaction, Phosphorus Availability and Plant Growth

A comparison of the data in Tables 11 to 13 with the corresponding data in Tables 17 to 19 reveals that in the Hartsells and Dewey soils, the highest amounts of phosphorus were absorbed by plants at a pH range of 5.2 to 6.1. In Grenada soil, on the other hand, the uptake of phosphorus increased progressively as the pH of the soil increased from 4.9 to 7.1. The highest total yields were obtained in Hartsells at a pH range of 5.4 to 6.1, while in the other soils the total yields increased up to pH 7.1, which was the highest pH reached.

For the same levels of phosphorus extracted by Bray's reagent, a higher uptake of phosphorus and yield of sorghum were obtained at a

pH of about 5.2 to 6.1 in Hartsells loam. In the other two soils for the same level of "available" phosphorus the uptake of this element increased up to a pH of 7.1.

CHAPTER V

DISCUSSION

The results of the present investigation provide useful information regarding fertilizer practices on three acid soils of Tennessee and give some significant indications about the nature of certain fundamental soil-plant relationships.

The beneficial effects of dolomitic limestone in promoting the growth and yield of plants on acid soils are amply borne out by the results of the present study. In Hartsells loam the highest total yields were obtained for a liming rate of 2 tons per acre, while in Dewey and Grenada silt loams significant yield increases were obtained for liming rates up through 6 tons per acre. An application of 2 tons of dolomite per acre to Hartsells soil raised the pH to an average value of 5.7 during the growth period of the plants. The highest yields of sorghum were observed at this pH rather than under more neutral conditions brought about by higher rates of lime application. These findings suggest the operation of some limiting growth factor, possibly the reduced availability of zinc.

The lime requirement of soils varies depending on several factors such as the texture and the nature of the soil colloidal complex. The fact that the pH of the Hartsells loam was raised through a larger range as compared to Dewey and Grenada silt loams for the same rates of lime application might point to the influence of texture, provided however, the colloidal properties of these soils were similar.

The proper time of lime application is a major factor in its efficient utilization and this, too, might vary with the properties of the soils involved. In Hartsells soil the yield of the second crop was higher than that of the first, presumably because the beneficial effects of lime increased with time.

The yield data obtained in these studies also correlated positively and significantly with the rates of phosphorus application. Stubblefield and DeTurk (35) pointed out that phosphorus is converted into living tissues and becomes part of the organic plant body, and as the absorption of increasing amounts of phosphorus is accompanied by a corresponding increase in growth, the percentage of phosphorus in the plant tissues will generally tend to be a constant. This was not the case in the present studies, because the phosphorus content of the plants was found to increase with increased rates of phosphorus application. Wright (45, 46) attributed the beneficial effects of large applications of superphosphate to acid soils mainly to the internal precipitation of aluminum by phosphorus, with excess phosphorus available for the metabolic processes of the plants. Although the data gathered in this study are not quite illustrative of this hypothesis, the simultaneous increase in the growth and phosphorus content of the plants might suggest the beneficial effect of phosphorus in combating the toxicity of aluminum.

The optimum rate of lime and phosphorus application to insure the best possible yields is an important factor in any intelligent

program for fertilization. The present study revealed that in Hartsells loam the highest yields of sorghum were obtained for a liming rate of 2 tons per acre and a phosphorus rate of 240 pounds of P_2O_5 per acre. In the Dewey and Grenada silt loams the yield increased progressively up to the highest rates used, viz., 6 tons of lime and 240 pounds of P_2O_5 per acre.

A knowledge of the causes of the low fertility of acid soils is essential for finding out the critical means of improving the crop yields on them. Lime promotes the growth of plants on acid soils and this beneficial effect of lime is attributed to different factors such as correcting of the soil acidity, remedying of nutrient deficiencies and combating of the toxic effects of certain cations. The results obtained in this study do not throw any additional light on the exact manner in which lime functions in acid soils, but the evidence from this investigation tends to favor the existing theories. There is no doubt that in Hartsells loam and Dewey silt loam dolomite has helped to remedy magnesium deficiencies, but this is not in itself a satisfactory explanation for the beneficial effects of lime on all acid soils. 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 significance of which will vary with different crops and soils. These authors hold the view that the poor growth of plants on acid soils cannot be attributed entirely to calcium deficiency brought about by a low exchangeable

calcium content and/or low degree of calcium saturation. The results of the present study lend support to this school of thought, because it has been shown that the level of calcium in the plants is fairly independent of the total supply in the soils and that the plants grown on unlimed acid soils may even contain a higher level of calcium than those which are grown on limed soils. Careful studies by Arnon and Johnson (4) with nutrient solutions and sand cultures have shown that many plant species can make normal growth at pH values as low as those encountered in most acid soils, and therefore, the hydrogen ion concentration cannot be considered as the cause of poor crop yields in these soils. Evidence is, therefore, very strongly in favor of the other view that toxic concentrations of certain cations such as aluminum and manganese would largely account for the low fertility of acid soils and for the poor growth of plants on them. Liming tends to reduce the concentrations of these cations in the soil solution and thereby to facilitate the growth of plants.

Lime at higher rates of application is known to repress the availability of added phosphorus and this has been borne out by the results of the present study. For liming rates of 0, 2, 4 and 6 tons of dolomite per acre the average phosphorus contents of the plants of the first crop on the Hartsells soil were 0.06, 0.14, 0.13 and 0.12 percent respectively. The corresponding values for Dewey and Grenada were respectively 0.09, 0.21, 0.19 and 0.16, and 0.18, 0.14, 0.14 and 0.13 percent. It is noteworthy that in Hartsells and Dewey the highest

absorption of phosphorus occurred for a liming rate of 2 tons per acre which raised the pH to about 5.5 to 5.8. In Grenada on the other hand, the highest absorption of phosphorus took place in the unlimed treatment (pH 4.4 to 4.6) and with increasing rates of lime application the percentage of phosphorus in the plants steadily decreased. For the four increasing rates of lime application the average levels of phosphorus in the plants grown in Hartsells during the second crop were 0.12, 0.13, 0.14 and 0.14 percent respectively. The corresponding values on Dewey and Grenada were respectively 0.13, 0.22, 0.18 and 0.20, and 0.15, 0.17, 0.14 and 0.15 percent. In this case the lowest level of phosphorus in all the soils is obtained for the unlimed treatments, while the highest percent of phosphorus is absorbed in Dewey and Grenada for the liming rate of 2 tons per acre. In Hartsells there is no significant difference between the levels of phosphorus in the plants for the different liming rates.

The repressing effect of lime on the absorption of added phosphorus by plants is generally attributed to the reversion of readily soluble phosphates to less soluble di- and octa- calcium phosphates in the pressence of excess calcium. The results of the present investigation suggest that there may be some other contributing factors also controlling the uptake of phosphorus by plants. On the strength of the evidence in literature it was indicated earlier that aluminum is probably precipitated as aluminum phosphate within the plant and this indication is further corroborated by the fact that at higher rates of

lime application, which results in decreased amounts of exchangeable aluminum in the soils, lower levels of phosphorus were found in the plants. This finding would suggest that higher levels of phosphorus would be found in plants in the presence of higher amounts of exchangeable aluminum in the soil. Furthermore, it is significant that only very low levels of phosphorus were abosrbed by the plants grown on the unlimed Hartsells and Dewey, although in the light of the view expressed herein, the higher levels of aluminum in these acid soils should have resulted in a higher absorption of phosphorus by plants. This may be attributed to the observed deficiency of magnesium in these soils which is considered as necessary for functioning as a carrier for phosphorus. Thus it would appear that the solubility of soil phosphorus and the levels of exchangeable aluminum and magnesium in the soil are all contributing factors which govern the levels of phosphorus in plants.

For this same reason the "available" phosphorus extracted by chemical reagents often fails to represent the amounts actually removed by crops. In these studies too, there was very little correlation between the amounts of phosphorus extracted by Bray's reagent and the amounts which the plants actually removed from the soils. This is because the "available" phosphorus determined by chemical extractants depends only on the solubility of soil phosphorus in them, whereas the amounts of phosphorus utilized by plants may also be controlled by the levels of exchangeable aluminum and magnesium in the soil.

Another interesting observation is that at the end of the experiment the amounts of phosphorus extracted by Bray's reagent from the soils in which the plants were grown had in many instances dropped to the level which had originally existed in the untreated sample. However, the difference between the extractable phosphorus in the incubated samples and these amounts did not represent the amounts actually removed by the crop. This is because the reactions occurring in a system like an incubated soil are very much different from those in a system such as a soil in which the plants are grown, and also because the solubility of the soil phosphorus alone is not the factor which governs its availability to plants.

The critical role of magnesium in the utilization of soil phosphorus by plants deserves more than passing consideration. Truog et al. (41) noticed an increasing level of phosphorus in peas with increasing concentrations of magensium and thought that this result confirmed the theory that magnesium functions as a carrier for phosphorus. These authors attribute the failure in many experiments to produce crops of higher phosphorus content through phosphorus fertilization to a lack of available magnesium. It is important that an adequate supply of magnesium be present in soils so that a more efficient utilization of added phosphatic fertilizers can be made. This would explain the superiority of dolomite as a liming material over other forms of lime which supply only calcium to the soil.

No significant observation regarding the effect of lime on the availability and absorption of potassium by plants has been revealed during the course of these studies, except that a high level of calcium has a repressing effect upon potassium. The liming of soils as a practical method of conserving the potassium supply has been emphasized by Thomas and Coleman (36) who indicate that an adequate supply of calcium in the soil solution helps to keep the potassium in the colloidal complex and prevent it from being lost in the drainage. According to Bear and Toth (6) an exchangeable Ca:K ratio of 13:1 in the soil enables the plant to absorb a liberal margin of potassium in excess of its requirements and yet not so much as to be a known waste of this element.

A remarkably constant cation equivalence of about 146 has been observed for sorghum in these investigations. Other workers (37, 43) have reported a higher value for cation equivalence for some other crops, but it is obvious that this would vary with the different species of plants. This constancy is maintained by the reciprocal relationship between Ca and Mg on the one hand and K on the other, as well as by the inverse relationship between Ca and Mg. In the present study an increased uptake of calcium occurred in magnesium deficient soils, and a decreased absorption of potassium in the presence of a higher level of calcium and magnesium. These results are in agreement with the view expressed by Bear and Prince (5) that every element will have two or more functions in the plant, one of

which is specific for that element and the other or others capable of being performed interchangeably by all elements. Once a minimum available amount of each of these elements is assured to meet the specific needs, there can be a wide range over which the relative proportions of these ions may vary.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A greenhouse study of the influence of four rates of lime and four rates of phosphorus on the yield and composition of sorghum grown on soil samples from three major soil types of Tennessee has been made. The soil types used were Hartsells loam, Dewey silt loam and Grenada silt loam. The changes in the pH and acidity characteristics of these soils for the same treatments during the growth period of the plants were also traced in a separate soil incubation experiment. The chief findings were as follows:

1. Significant growth and yield response to the applications of lime and phosphorus on all the three soils studied were obtained. The highest total yield of sorghum in Hartsells was obtained for a liming rate of 2 tons of dolomite per acre, and a phosphorus rate of 240 pounds of P_2O_5 per acre. In the Dewey and Grenada silt loams the yield increased progressively up to the highest levels of fertilizers used, viz. 6 tons of lime and 240 pounds of P_2O_5 per acre.
2. The three soils differed in their capacity to produce and in the nature of their interaction with lime. Grenada silt loam generally gave the best total yields at all levels of lime and phosphorus treatments, when compared to the other two soils. In Hartsells loam the second crop yield was higher than the first, evidently because the beneficial effects of lime on this soil continued to increase during the entire growth period.

3. Soil incubation studies showed that the soils differed in the quantities of lime required to raise their pH through the same range. "Available" phosphorus determined by Bray's method showed an increase in the amounts of extractable phosphorus with increasing rates of phosphorus application and a tendency for the extractable phosphorus to decrease to a minimum amount during the period of four to six weeks and then to increase again.

4. Comparison of the results of the greenhouse study with those of the soil incubation experiment shows that in the Hartsells loam and the Dewey silt loam the highest amounts of phosphorus were absorbed by plants at a pH range of about 5.2 - 6.1. In Grenada silt loam the uptake of phosphorus increased progressively as the pH of the soil increased from 4.9 to 7.1. The highest total yields were obtained in Hartsells at a pH range of 5.4 to 6.1 while in the other two soils the total yields increased up to a pH of 7.1 which was the highest pH reached.

5. "Available" phosphorus at the end of the experiment in the treated soils in which the plants were grown had in many instances dropped to the level in the untreated soil before the experiment. However, the difference between the "available" phosphorus in the incubated samples and these amounts were not correlated with the amounts which the plants had actually removed.

6. There was some indication that the exchangeable aluminum as governed by the soil reaction, the availability of magnesium and the solubility of soil phosphorus were among the contributing factors which controlled the utilization of phosphorus by plants. For this reason the "available"

phosphorus as usually determined, which depends almost entirely on the solubility of soil phosphorus in certain chemical reagents, may not be a proper index of the amounts of phosphorus actually removed by plants.

7. Sorghum grown on the three different soils showed a cation equivalence constancy of about 146 me./100 g. plant material. This constancy was maintained by a reciprocal relationship between Ca and Mg on the one hand and K on the other, and by an inverse relationship between Ca and Mg.

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