



Phosphorus fertility study on a Michoacan, Mexico soil
by Luvern Leo Resler

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree
of Master of Science in Soils

Montana State University

© Copyright by Luvern Leo Resler (1965)

Abstract:

The effect of rates of phosphorus, Calcium, and potassium were tested on the surface 25 centimeters of an uncultivated Sierra Tarasca soil of Michoacan, Mexico.

The experiment was conducted in the greenhouse at Montana State College at Bozeman. A series of phosphate dressings were applied in pot culture experiments in order to determine the extent to which sorghum plants respond. Sorghum yield data, the percent recovery of applied phosphorus, and phosphorus fraction content were used as criteria of response to test the effect of the interactions.

The addition of phosphorus to the soil was effective in increasing the vegetative growth of sorghum when calcium was added but less significant alone.

Phosphorus and potassium without calcium appear to have relatively little fertilizer value at the rates used in this study.

Although the vegetative yield increased with phosphorus and calcium additions, the recovery of added phosphorus by plants and chemical extractions decreased, indicating phosphorus fixation.

The aluminum phosphate increased markedly with phosphorus additions. Calcium and iron phosphates also increased, but to a lesser degree.

PHOSPHORUS FERTILITY STUDY ON A MICHOACAN, MEXICO SOIL

by

Lavern Leo Resler

A THESIS

Submitted to the Graduate Faculty

in

partial fulfillment of the requirements

for the degree of

Master of Science in Soils

at

Montana State College

Approved:


Head, Major Department


Chairman, Examining Committee


Dean, Graduate Division

Bozeman, Montana
June 1965

ACKNOWLEDGMENT

I want to express my sincere appreciation to my major advisor, Dr. M. G. Klages, Professor of Soils; Montana State College, for his guidance and valuable suggestions during the various phases of the study and manuscript preparation. I am additionally indebted to my faculty advisory committee; Dr. A. H. Post; Dr. A. H. Ferguson, Dr. H. A. Kittams, and the late Dr. J. C. Hide of the Department of Plant and Soil Science for their advice and encouragement, and to Dr. E. Skogley for substituting on my examining committee. A special thanks is extended to the Director of the International Cooperation Center at Montana State College; Dr. Harvey F. Baty. The study could not have been made without his generous assistance during the initial work. I also want to thank the Carnegie Foundation for its financial support and The Rockefeller Foundation in Mexico City, whose personnel and research reports were helpful in laying the groundwork for the study. My appreciation is extended to Mrs. Lilah Duncan for typing the manuscript. I also wish to express my admiration for my wife's patience during the preparation of this manuscript.

TABLE OF CONTENTS

VITA	ii
ACKNOWLEDGMENT	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	v
LIST OF FIGURES	vi
ABSTRACT	viii
CHAPTER I. INTRODUCTION	1
CHAPTER II. REVIEW OF LITERATURE	3
CHAPTER III. MATERIALS AND METHODS	10
Soil Description	10
Collection and Treatment of Soil	11
Experimental Design	11
Soil Analytical Procedures	12
Plant Analytical Procedures	14
CHAPTER IV. RESULTS AND DISCUSSION	15
Crop Yield Response	15
Mineral Uptake and Plant Concentration	20
Phosphorus Fractionation	27
Applied Phosphorus Recovery	28
CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS	30
APPENDIX	31
LITERATURE CITED	44

LIST OF TABLES

Context Tables

TABLE	PAGE
I. SOME PHYSICAL AND CHEMICAL PROPERTIES OF THE SOIL SURFACE 25 CENTIMETERS	10
<u>Appendix Tables</u>	
II. SOIL PROFILE DESCRIPTION	32
III. TREATMENTS APPLIED TO THE EXPERIMENTAL POTS AND THE CORRESPONDING FIRST CROP, SECOND CROP, AND TOTAL CROP YIELD RESPONSE	33
IV. ANALYSIS OF VARIANCE - FIRST CROP VEGETATION WEIGHT IN GRAMS	34
V. ANALYSIS OF VARIANCE - SECOND CROP VEGETATION WEIGHT IN GRAMS	35
VI. ANALYSIS OF VARIANCE - TOTAL CROP VEGETATION WEIGHT IN GRAMS	36
VII. CONCENTRATION OF PHOSPHORUS IN PLANTS AND PHOSPHORUS REMOVED FROM THE SOIL BY THE VEGETATIVE GROWTH OF SORGHUM ASSOCIATED WITH VARIOUS FERTILIZER TREATMENTS	37
VIII. CONCENTRATION OF CALCIUM IN PLANTS AND CALCIUM REMOVED FROM THE SOIL BY THE VEGETATIVE GROWTH OF SORGHUM, ASSOCIATED WITH VARIOUS FERTILIZER TREATMENTS	38
IX. CONCENTRATION OF POTASSIUM IN PLANTS AND POTASSIUM REMOVED FROM THE SOIL BY THE VEGETATIVE GROWTH OF SORGHUM ASSOCIATED WITH VARIOUS FERTILIZER TREATMENTS	39
X. EXTRACTED SOIL PHOSPHORUS FRACTIONS, ASSOCIATED WITH FERTILIZER ADDITIONS	40
XI. APPLIED PHOSPHORUS RECOVERY OF PLANTS AND CHEMICAL EXTRACTIONS, EQUILIBRATED BY SETTING THE NO PHOSPHORUS TREATMENT AT ZERO AND DETERMINING THE DIFFERENCE BETWEEN PHOSPHORUS ADDED AND PHOSPHORUS REMOVED	41

LIST OF FIGURES

Context Figures

FIGURE	PAGE
1. SORGHUM YIELD AS AFFECTED BY PHOSPHORUS ADDITIONS ASSOCIATED WITH CALCIUM AND POTASSIUM FERTILIZATION (Ca at 4500 ppm., K at 50 ppm.)	16
2. SORGHUM GROWTH INDICATING THE RESPONSE TO VARIOUS PHOSPHORUS APPLICATIONS COUPLED WITH POTASSIUM AND CALCIUM	17
3. SORGHUM GROWTH INDICATING THE RESPONSE TO VARIOUS PHOSPHORUS APPLICATIONS COUPLED WITH CALCIUM	17
4. SORGHUM GROWTH INDICATING THE LACK OF RESPONSE TO VARIOUS PHOSPHORUS APPLICATIONS ALONE	18
5. SORGHUM GROWTH INDICATING THE LACK OF RESPONSE TO VARIOUS PHOSPHORUS APPLICATIONS COUPLED WITH POTASSIUM, WITHOUT CALCIUM	18
6. PHOSPHORUS REMOVED BY PLANTS CORRESPONDING TO PHOSPHORUS APPLICATIONS, RELATED TO CALCIUM AND POTASSIUM FERTILIZATION	21
7. CONCENTRATION OF PHOSPHORUS IN PLANTS CORRESPONDING TO PHOSPHORUS APPLICATIONS, RELATED TO CALCIUM AND POTASSIUM FERTILIZATION	21
8. CALCIUM REMOVED BY PLANTS CORRESPONDING TO PHOSPHORUS APPLICATIONS RELATED TO CALCIUM AND POTASSIUM FERTILIZATION	22
9. CONCENTRATION OF CALCIUM IN PLANTS CORRESPONDING TO PHOSPHORUS APPLICATIONS, RELATED TO CALCIUM AND POTASSIUM FERTILIZATION	22
10. POTASSIUM REMOVED BY PLANTS CORRESPONDING TO PHOSPHORUS APPLICATIONS WITH AND WITHOUT Ca AND K	23
11. CONCENTRATION OF POTASSIUM IN PLANTS CORRESPONDING TO PHOSPHORUS APPLICATIONS, WITH AND WITHOUT Ca AND K	23

Appendix Figures

12. ALUMINUM PHOSPHATE EXTRACTED FROM THE SOIL AS AFFECTED BY PHOSPHORUS ADDITIONS ASSOCIATED WITH CALCIUM AND POTASSIUM FERTILIZATION	42
--	----

13.	CALCIUM PHOSPHATE EXTRACTED FROM THE SOIL AS AFFECTED BY PHOSPHORUS ADDITIONS ASSOCIATED WITH CALCIUM AND POTASSIUM FERTILIZATION	42
14.	IRON PHOSPHATE EXTRACTED FROM THE SOIL AS AFFECTED BY PHOSPHORUS ADDITIONS ASSOCIATED WITH CALCIUM AND POTASSIUM FERTILIZATION	43
15.	AVERAGE CALCIUM, ALUMINUM, AND IRON PHOSPHATE EXTRACTED FROM THE SOIL CORRESPONDING TO PHOSPHORUS ADDITIONS ASSOCIATED WITH CALCIUM AND POTASSIUM FERTILIZATION	43

ABSTRACT

The effect of rates of phosphorus, calcium, and potassium were tested on the surface 25 centimeters of an uncultivated Sierra Tarasca soil of Michoacan, Mexico.

The experiment was conducted in the greenhouse at Montana State College at Bozeman. A series of phosphate dressings were applied in pot culture experiments in order to determine the extent to which sorghum plants respond. Sorghum yield data, the percent recovery of applied phosphorus, and phosphorus fraction content were used as criteria of response to test the effect of the interactions.

The addition of phosphorus to the soil was effective in increasing the vegetative growth of sorghum when calcium was added, but less significant alone.

Phosphorus and potassium without calcium appear to have relatively little fertilizer value at the rates used in this study.

Although the vegetative yield increased with phosphorus and calcium additions, the recovery of added phosphorus by plants and chemical extractions decreased, indicating phosphorus fixation.

The aluminum phosphate increased markedly with phosphorus additions. Calcium and iron phosphates also increased, but to a lesser degree.

CHAPTER I

INTRODUCTION

Preliminary soil fertility studies were conducted in the Sierra Tarasca of the State of Michoacan, Mexico, in 1960 (29). The selected area lies generally within a triangle made by connecting Pátzcuaro, Acambaro, and Ario de Rosales. These studies, carried on mainly by personnel of The Rockefeller Foundation working with local Mexican government personnel and farmers, indicated that applications of nitrogen, phosphorus, potassium and calcium have, in some cases, relatively little effect on crop yields, even though unfertilized yields were low. In further studies phosphorus was given major consideration since preliminary observations indicated that the soils were particularly deficient in this element. One of the interesting results of this study was the relatively poor crop response to commercial fertilizer forms of phosphorus along with other elements in relation to chicken manure and phosphorus. The need for further information concerning the adverse effects of general deficiencies or toxicities and phosphorus fixation was pointed out.

The soil used for the present research project was taken from the Sierra Tarasca area between San Gregorio and Opopeo, in the State of Michoacan, Mexico, in March 1961. This area is about 19 degrees north latitude with an elevation of approximately 2600 meters.^{1/} The mean annual temperature is about 10 degrees Centigrade, with the general frost-

^{1/} One meter equals approximately 3.28 feet.

free period being from mid-March to mid- or late October.^{2/}

The soils of this area are subjected to periods of extremely low rainfall during the winter and spring months, October to the middle or latter part of June, and a rainy season, during which approximately 100 centimeters of rain falls, which corresponds to the remaining part of the year.^{3/}

One of the most striking facts is that corn is practically the only cultivated crop. The general practice is to take one crop of corn every two years. The primary reason given for this is the need to replenish fertility by a year of rest. It is doubtful that this is a valid reason. It is more likely that the type of corn used requires residual moisture, which is stored during the fallow year. By leaving the fields one rainy season, sufficient moisture is stored so that corn can be planted in March and reach physiological maturity before early frosts occur.^{4/}

This research project was primarily concerned with the effects of varying levels of phosphorus fertilization as affected by calcium and potassium additions under greenhouse conditions and with investigating the possible phosphorus fixation mechanisms.

^{2/} $0(^{\circ}\text{C} \times 1.8) + 32 = ^{\circ}\text{F}$.

^{3/} 1 centimeter equals approximately 0.3937 inches.

^{4/} Correspondence with Dr. R. E. Laird, Rockefeller Foundation, Mexico City, Mexico.

CHAPTER II

REVIEW OF LITERATURE

Phosphate fixation by acid soils has been the subject for research by many investigators, and various theories relative to the mechanism of such fixation have been evolved.

In general, authors such as Chang and Jackson (4), (6), Dean (13), Hibbard (16), and Pierre and Norman (23), indicate that inorganic phosphates in the soil can be classified into four main groups: Calcium phosphate, aluminum phosphate, iron phosphate, and the reductant-soluble phosphate extractable after the removal of the first three forms. It is widely accepted that iron, aluminum and calcium phosphates also include absorbed and surface-precipitated phosphates associated with soil particles.

Harris (15) suggests that the available phosphorus level of soils can be accurately estimated by water extraction and that the water-soluble phosphorus is a good indicator of the phosphorus fixation capacity of some soils with a history of phosphorus fertilization. This method assumes that the level of water-soluble phosphorus is directly related to the equilibrium phosphorus concentration in the soil solution. Nevertheless, he suggests that, just as a lime requirement test is valuable in addition to a pH determination, a phosphorus fixation capacity determination is of value in addition to a phosphorus soil test. He further indicates fixation of phosphorus added to a soil proceeds rapidly in its initial stages and although the rate decreases, it continues for many weeks. Results have been reported by Hibbard (16) and Olson (22) which indicate that phosphorus fixation under laboratory conditions is nearly

complete (80 to 100%) within a few hours. Because of this rapid fixation, short term experiments have been used to measure the capacity of soils to fix phosphorus in the unavailable form.

Many researchers (2); (4), (5), (13), (16) point out the importance of knowledge concerning the specific chemical forms of inorganic phosphates in understanding the chemistry of soil phosphorus and also illuminating problems concerning soil genesis (17) and soil fertility (23), (30), (32) associated with phosphorus. The distribution of various forms of inorganic phosphorus in the soil is no doubt controlled by the activities of the various ions in the soil, in turn reflecting soil pH, age, drainage and mineralogical nature (6). Fractionation of soil phosphorus also permits tracing the fate of applied phosphate fertilizer under different soil conditions, possibly giving some insight into a balanced fertilizer application program and expected response.

Based on the pH-solubility relationships, when the soil phosphates are compared with those of known phosphate minerals, it is generally accepted that the inorganic phosphates are dominantly bonded by calcium in calcareous soils (14) and by aluminum or iron in acid soils (10). This is supported by Dean (11) in his study on the fate of the phosphate fertilizer applied to two Rothamsted soils, which indicates that acid-soluble phosphate increased in calcareous soils and that the alkali-soluble phosphate increased in acid soils.

Iron, aluminum, and calcium have been shown by Lawton (20) to be important factors in phosphorus fixation, but the total amounts present

did not correlate significantly with increases in the soil test values.

Bass and Sieling (2) developed a method for determining the relative phosphorus fixing capacity of acid soils in which the amount of iron and aluminum extracted was found to be a measure of the relative phosphorus fixing capacity of the soil. In this work the results indicated that there is no absolute value for phosphate-fixing capacity of a soil.

Phosphate fixation by acid soils and soil colloids is highly correlated with the amounts of active aluminum and iron associated with them, as shown by Coleman (9) and Ghani and Islam (14). Chang and Jackson (4) found that although there is a relationship between the phosphorus fixation capacity of soils and the extractable aluminum and iron, that the extractable aluminum and iron were not a quantitative measure of this capacity. They further suggest that, since the various forms of phosphates have different solubilities, their distribution might give an indication of the availability of phosphorus to plants in the soil.

Work by Dean and Rubins (12) indicates the latter apparently is largely determined by the amount or extent of the phosphate surface of the various chemical species. The extraction of active iron and aluminum from acid soils by citric acid solution was found by Bass and Sieling (2) to be an excellent basis for determination of phosphate fixing capacity, and was chemically equivalent to direct measurement of phosphate fixing capacity by the Piper method (24).

Cole and Jackson (7) have demonstrated the formation of iron and aluminum phosphate crystals under controlled conditions simulating possible soil conditions, and related the solubility equilibrium constant

of dihydroxy aluminum dihydrogen phosphate to a mechanism of phosphate fixation in soils. Precipitation of the variscite species in soils takes place in the form of its crystals as a new, separate soil phase, and therefore its precipitation is distinct from adsorption. The solubility equilibrium constant of dihydroxy aluminum dihydrogen phosphate (variscite crystal species) and dihydroxy iron dihydrogen phosphate (strengite crystal species) is pointed out by Cole and Jackson (8) to be of such magnitude as to cause formation of these species in acid soils containing reactive aluminum and iron when soluble phosphate fertilizers are added. They further state that dihydroxy dihydrogen phosphates of aluminum are sufficiently soluble to furnish phosphorus for plant growth, as has been demonstrated by Truog (34). Additional work (8) suggests that the presence of relatively soluble sources of aluminum such as gibbsite and kaolinite and, to some extent montmorillonite, may decrease the concentration of phosphorus in the soil solution to a point at which phosphorus availability becomes the limiting factor in plant growth.

Localized placement of phosphate in bands precipitates the local active aluminum and iron, and the phosphorus concentration shifts to a higher equilibrium concentration, except as calcium enters the equilibrium system, as shown by Cole and Jackson (8).

The effect of increasing OH concentration on the release of phosphorus from variscite has been shown (8) through the decrease in aluminum activity. Other anions also increase the concentration of phosphorus in solution if they decrease the effective concentration of aluminum either

by the formation of stable soluble complexes or by precipitation of the aluminum. The replacement of phosphorus from precipitated phosphates of aluminum and iron by various organic anions has been demonstrated by Struthers (31) and Swenson (32), and relates phosphorus availability in soils to the formation of various organic acids during active decomposition of organic matter.

In work by Chang and Jackson (6) the distribution of soil inorganic phosphorus was found to measure the degree of chemical weathering, the chemical weathering sequence being calcium, aluminum, iron and occluded phosphate, in order. The latter category includes reductant soluble iron-phosphate and aluminum-iron phosphate occluded in iron oxide. They found that in highly weathered Latosols only a very small amount of phosphorus is present as calcium phosphate (1%) and aluminum phosphate (0-3%), with most of the phosphorus being present in the form of iron phosphate (10-13%) and occluded (reductant soluble) phosphate (66-78%).

The practice of liming acid soils results in a number of beneficial effects with respect to crop growth. One of these is considered to be an increase in the availability of soil and fertilizer phosphorus. Neller (21) points out that in acid soils lime is generally credited with the ability to make more of the added phosphate available to crops, particularly for soils high in iron and aluminum. The data consistently show that use of varied amounts of lime had no effect on the percentage uptake by oats and millet of phosphorus in currently applied superphosphate for Rutlege fine sand and sandy loam soils of Florida. In the fine sand

lime caused a marked reduction in the phosphorus content of the plants. An explanation of the rather unusual effect is that lime converts the water-soluble monocalcium phosphate of superphosphate to the less soluble dicalcium phosphate and possibly in some loci to tricalcium phosphate. In additional work by Neller (21) lime had an opposite effect in Marlboro fine sandy loam in that it caused the phosphorus content of oats to be somewhat higher. This soil contains considerably more iron and aluminum than Rutlege and the lime probably resulted in formation of phosphate compounds that were more soluble than those of iron and aluminum. Albrecht and Klemme (1) report that application of limestone and superphosphate to mineral soils approximately doubled the phosphorus content of lespedeza forage over that contained in plants from soils receiving super-phosphate alone.

Work by Robertson (28) on liming Florida soils relatively low in residual phosphorus indicates an increased availability of applied phosphorus up to pH 6 to 6.5 when the sesquioxides were high, but had no effect where the sesquioxides were low. Liming these soils above 6 to 6.5 caused the percentage of phosphorus in the plant from the fertilizer to level off or decline, probably 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. Uptake of phosphorus from currently applied superphosphate was highest from the soils high in sesquioxide content irrespective of rate of liming. Soil and plant analysis indicated that

the differences might be due to calcium nutrition. Prince (25) has shown that it was possible to improve the availability of phosphorus in soils that fix phosphorus by adding lime. Cole and Jackson (8) suggest that the increased release to the crop of phosphorus from aluminum and iron phosphate is due at least partially to the lowered aluminum and iron activity resulting from increased pH through liming.

Personnel from the Rockefeller Foundation (29) found that twenty tons of chicken manure plus 200 kilograms of P_2O_5 per hectare on some Tarascan soils gave a much larger increase in corn production than that obtained with nitrogen and phosphorus alone.^{5/} Tisdale and Nelson (33) suggest the decomposition of organic material is accompanied by the evolution of appreciable quantities of carbon dioxide which, when dissolved in water, forms carbonic acid which is capable of decomposing certain primary soil minerals over a wide pH range from calcareous to acid soils.

^{5/} One hectare is 10,000 square meters; therefore kilograms per hectare is approximately equal to pounds per acre.

CHAPTER III

MATERIALS AND METHODS

Soil Description

The soil of this mountain area is of the type classified by Whiteside as being very similar to the Ando soils which were first recognized in Japan.^{6/} Adequate soil classification and survey data are lacking for this area. The soil formed from volcanic ash with the surface soil weathered to silt loam (Table I) and has a gently rolling topography with a few stony patches and higher hills. The soil sample used for laboratory and greenhouse studies was taken from an uncultivated site which had been cleared of coniferous forest two seasons previously and replaced with native grass.

TABLE I. SOME PHYSICAL AND CHEMICAL PROPERTIES OF THE SOIL SURFACE
25 CENTIMETERS.

SILT %	CLAY %	SAND %	O.M. %	TOTAL N %	pH
79.4	13.4	7.2	9	.20	5.5

AVAILABLE P. ppm.	AVAILABLE K. ppm.	AVAILABLE S. ppm.	C.E.C. me/100 g.	Ex.H me/100 g.	C/N
-------------------------	-------------------------	-------------------------	---------------------	-------------------	-----

The drainage is good, the soil having rapid permeability and low ground water.^{7/} The soil is high in iron and aluminum which presents a phosphorus fixation problem, and aluminum toxicities may occur. The slope

^{6/} Personal correspondence with Dr. E. P. Whiteside, Professor of Soil Science, Michigan State University, East Lansing, Michigan.

^{7/} Laboratory measurements gave an average distilled water flow of 1.74 inches per hour with 4-inch soil columns with an additional 1-inch head.

of the sampling area is approximately 8% with very little erosion. The root distribution is abundant above the hard massive "tepetate" layer at 98 centimeters (Table II). In places many "tuza" burrowing rodents are present in old fence rows. Ballados (steep sided narrow trenches) are used to keep cattle out of the cultivated fields.

Collection and Treatment of the Soil

A 100-kilogram sample of soil was collected from the top 25 centimeters of the soil profile, thoroughly mixed, and approximately 30 kilograms were placed in a metal container (10-gallon milk can). The can was sealed and shipped to Laredo, Texas, where it was vacuum fumigated with methyl bromide, and subsequently steam sterilized under 15 pounds pressure for 3 hours at Montana State College, permitting the entire volume to reach a constant temperature.^{8/} The soil was then air dried, thoroughly mixed, and 300-gram aliquots placed in plastic pots with top diameters of 10 centimeters.

Experimental Design

A completely randomized greenhouse experiment was designed using 24 different treatments duplicated. The treatments consisted of 6 levels of phosphorus (0, 25, 50, 100, 200, and 400 ppm.), 2 levels of calcium (0 and 4500 ppm.), and 2 levels of potassium (0 and 50 ppm.) as a complete factorial. Nitrogen and sulfur were applied to all pots in a split application before planting and immediately following the

^{8/} This was in accordance with specifications given by the United States Department of Agriculture; Plant Quarantine Division; 209 River Street; Hoboken; New Jersey.

harvest of the first crop. Total nitrogen and sulfur rates were 100 and 10 parts per two million (100 and 10 kilograms per hectare), respectively.

The phosphorus dressings, from standardized dilute phosphoric acid, were applied at the outset of the experiment. The potassium was supplied by potassium chloride dissolved in water and applied at the beginning of the study. The rate of calcium addition was sufficient to increase the pH to about 6.8. This proved to be 600 milliliters of a saturated calcium hydroxide solution which was equivalent to 9000 kilograms per hectare.

Sorghum variety Martins (Sorghum vulgare) was planted 3 seeds to a pot for each crop. The first crop was harvested 42 days after planting and the second crop 32 days after planting, at about the 7-leaf stage of growth. The crop yield data was statistically analyzed, separately for each crop, and total crop response derived by adding the individual crop responses.

Soil Analytical Procedures

All soil chemical and physical analyses were conducted on aliquots of soil held back from the cropping phase, except the phosphorus fractionation. It was conducted on the soil after the second crop was removed and the soil air dried and mixed.

All phosphate analyses are given as parts per million P for oven-dry soil. The available phosphorus was extracted with sodium bicarbonate as described by Jackson (19, p. 163). Phosphorus fractionation was

conducted according to the procedure outlined by Chang and Jackson (4).

The aluminum phosphate was extracted with neutral 0.5 N ammonium fluoride and the iron phosphate subsequently extracted from the same sample with 0.1 N sodium hydroxide, both at room temperature. The calcium phosphate was then removed from the same sample with 0.5 N sulfuric acid.

The pH measurements were conducted on a 1:2 soil-water dilution, left for an hour to reach equilibrium, and determined with a Beckman Model H-2 glass electrode pH meter.

The percent organic matter was determined using the chromic acid wet digestion oxidation method by Jack (19, p. 206).

The total nitrogen determination, excluding nitrates, was conducted using the modified Kjeldahl method given by Jackson (19, p. 183).

The carbon was estimated by multiplying the percent organic matter by the coefficient 0.58, since soil organic matter is generally considered to have about 58% carbon. This was coupled with the total nitrogen value, as determined by the Kjeldahl method, to give a carbon-nitrogen ratio.

Total cation exchange capacity was determined by leaching the soil with ammonium acetate as described in the Agricultural Handbook No. 60 (26).

Mechanical analysis was accomplished by dispersing with 0.1 percent Calgon solution according to the procedure by Brown (3) and pipette samples withdrawn at the depth and time designated by Jackson (18) for silt (less than 50 microns) and clay (less than 2 microns).

Available sulphur was determined by extracting with ammonium acetate and measured by turbidity utilizing barium chloride.^{9/}

The exchangeable hydrogen was removed by leaching with barium acetate and then determined titrimetrically using the procedure of Jackson (19, p. 74).

Plant Analytical Procedures

The plants were harvested at the soil level, the top material dried at 70° C., broken, placed in a beaker, ashed, and taken up in hydrochloric acid according to the procedure given by Jackson (19, p. 334). The solution phosphorus was determined by the chlorostannous reduced molybdophosphoric blue color method as described by Jackson (19, p. 144). Potassium in solution was determined by flame emission on a Model B Beckman Spectrophotometer. Solution calcium was determined by the versenate method (19, p. 64). All plant minerals are listed as concentration in parts per million of plant tissue in addition to total uptake in milligrams.

^{9/} Klages, M. G., Procedures in Use at the Soil Testing Laboratory, mimeographed circular No. 50; Montana State College, Bozeman, Montana. July 1963.

CHAPTER IV
RESULTS AND DISCUSSION

Crop Yield Response

The addition of phosphorus alone had an effect upon the vegetative yield of sorghum. The total crop data (Appendix; Table III) (Fig. 1) indicate that the response was somewhat erratic, but with the exception of the 100 parts per million phosphorus treatment the total yield in all cases was larger than the check with increased phosphorus applications. The phosphorus treatments were statistically significant at the 5% level for both crops and total yield (Appendix, Tables IV, V, and VI).

Potassium addition alone gave statistically significant results at the 5% level in the second and total crop analyses of variance (Appendix, Tables V and VI). In the first crop there was actually a slight decrease in yield where potassium was used (Appendix; Table III). The yield from each individual pot was very small; therefore, a genetic difference such as seed size may have affected the one duplicate of the check, which is about 50% larger than the other (Appendix; Table III). In all other cases individual pot yields were slightly larger when potassium was applied. Figure 2 indicates the sorghum growth response with varied phosphorus rates when potassium and calcium were also supplied. Figure 3 indicates the same circumstances except for the deletion of potassium.

Calcium alone, in all cases, increased the sorghum yield over that of the check. The calcium response was significant at the 5% level in both crops and in total yield (Appendix; Tables IV, V, and VI). Figures 4 and 5 indicate the lack of plant growth response where phosphorus and

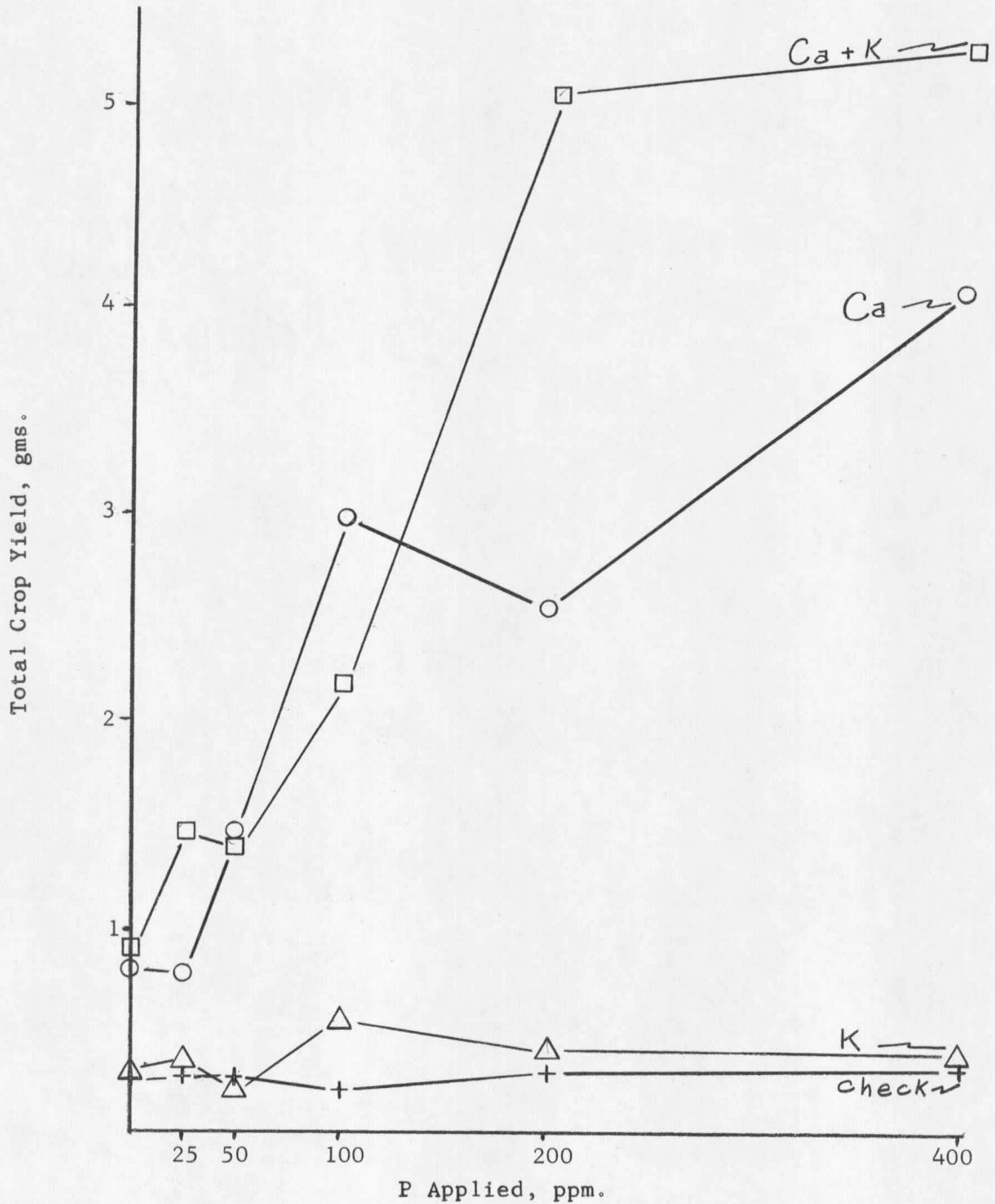


FIGURE 1. Sorghum yield as affected by phosphorus additions associated with calcium and potassium fertilization (Ca at 4500 ppm., K at 50 ppm.)

