

EFFECTS OF LIME AND
FERTILIZER UPON PLANT GROWTH AND
COMPOSITION

Thesis for the Degree of Ph. D.

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James F. Power

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EFFECTS OF LIME AND FERTILIZER UPON
PLANT GROWTH AND COMPOSITION

By
James F. Power

A THESIS

Submitted to the School of Graduate Studies of
Michigan State College of Agriculture and
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of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

Department of Soil Science

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THESIS

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ABSTRACT

A greenhouse experiment was preformed in which it was desired to study the effects of lime and fertilizers upon plant growth and composition in an attempt to determine the effects of soil fertility upon the nutritive value of forage. The experimental crops were soybeans, oats, and alfalfa, and the soil treatments were various combinations of four different levels of available soil phosphorus and potassium, and four pH levels using both calcium carbonate and a calcium-magnesium carbonate mixture. The entire above ground parts of the plants were harvested at the close of the vegetative stage of growth, dried, weighed, and analyzed chemically for mineral and feedstuff constituents.

The results showed that adding magnesium to the liming material altered only the calcium and magnesium contents of the plants appreciably. Dry weight yields were not affected. Soybean yields increased steadily as soil pH was increased from 4.7 to 6.8. The dry matter production of oats and alfalfa was not significantly increased by liming when the soil pH was over 5.8. Only the growth of oats responded to phosphorus fertilization. Potassium fertilization did not significantly increase the dry weight yield of any crop.

Increasing soil pH increased the percentages of crude fiber, ether extract, protein, iron, and calcium in the soybeans. Boron, N-free extract, phosphorus, and manganese were decreased. This soil treatment increased the calcium content, but decreased the percentages of ash and minor elements in the

oats. In the alfalfa the percentages of protein, ash, and calcium were increased while boron, iron, and manganese were decreased.

Phosphorus fertilization increased the ash, ether extract, protein, sodium, and phosphorus contents of the soybeans but decreased the percent N-free extract and boron. In the oats, N-free extract, phosphorus, and calcium were increased, and iron and protein were decreased. The concentrations of ash, phosphorus, and iron in the alfalfa were increased by phosphorus fertilization, and only sodium and copper were decreased.

Potassium fertilization of the soils increased the percentages of ash, potassium, and manganese in the soybeans, and decreased only the percent magnesium. Ash and potassium were also increased in the oats, but ether extract, sodium, boron, and iron were decreased. In alfalfa, only ash was increased in concentration, while sodium, calcium, and magnesium were decreased.

The percent base saturation of the soil exchange complex appeared to be a better measure of the fertility status of the soil than cation ratios. Total milliequivalents of bases in 100 grams of plant material were increased in all crops when the percent base saturation of the soil was increased.

Considering protein, phosphorus, calcium, crude fiber, iron, and ash to be the constituents most important in determining the nutritive value of the plant, it appeared that phosphorus fertilization increased the nutritive value of all three crops. The effect of liming on the nutritive value of the crops was smaller and much more variable. Potassium fertilization appeared to have no appreciable effect in this respect.

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INTRODUCTION

The chemical composition of a plant is the result of many factors. These factors may be divided into two categories; the internal variables and the external variables. The first class consists of the genetic factors of the plant; the species and variety. The second category includes the environmental complex; climate, soil type, competition and association with other plants, stage of maturity, supply of available soil nutrients, and so forth. It is with the last of these factors, the effect of the supply of available soil nutrients upon the composition of plants, with which this work is concerned. It is one phase of an inter-departmental project at Michigan State College in which the effects of soil fertility upon the nutrition of dairy cattle and upon the nutritional value of their milk is being studied (28). It was undertaken with the objective of measuring the effects of fertilization with calcium, magnesium, phosphorus, and potassium at various levels upon the nutritional value of forage crops in so far as such a value can be assayed by total chemical analyses of the plants.

Because of the wide variations possible in the environmental complex, the results of other similar studies are not necessarily applicable to this work. Therefore, this experiment was considered to be necessary in order to determine, under a given environmental complex, not only the

2.

direction and magnitude of these variations in plant composition, but also to determine some of the natural phenomena which govern these changes. Such, then, are the objectives of the work reported in this thesis.

REVIEW OF LITERATURE

Several thorough reviews of the effects of lime and fertilizers upon the chemical composition of plants have appeared in the literature in recent years (15, 24, 37, 38, 45, 47, 53, 55, 60, 71, 82, 86, 90, 107). Most of these publications were concerned mainly with the effects of soil amendments upon the mineral and protein contents of the plant. The literature is notably lacking in information on the effects of liming and fertilization upon the feedstuff composition of forage plants (52, 85). Several papers (4, 18, 30, 31, 32, 33, 34, 39, 42, 54, 57, 67, 73, 83, 95, 96, 105) have appeared citing the changes that occur in some of the organic fractions, particularly in the vitamin, organic acid, and different forms of organic nitrogen found in plants as a result of fertilization. The influence of fertilization upon the nutritional value of plants as measured by feeding trials has been studied both in the fields of agronomy and animal science (15, 19, 28, 52, 53, 55, 64, 70, 84).

In reviewing the results published concerning the effects of liming and fertilizing upon the chemical composition of plants, there exists much conflicting and contradictory data. In certain cases, the addition of a particular soil amendment increased the percent of another chemical constituent in the plant, while in other cases it caused a decrease. It should be remembered that variations in the

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supply of available soil nutrients is only one of many factors determining the chemical composition of plants. Some of the other factors, such as location, climate, and soil type, often exert a greater influence upon the composition of a plant than does the level of soil fertility or the fertility balance (15, 55, 82, 87, 90, 99). For instance, Beeson (15) reported that unfertilized forage in Michigan was usually higher in minerals than heavily fertilized forage in Alabama.

The influence that liming exerts upon plant composition is varied. It is difficult to separate the effects of increased calcium supply from the effects of increased pH when lime is added. However, under conditions of practical agriculture, probably most of the changes that occur in plant composition with the application of lime to acid soils can be attributed to the variations in the availability of the other soil nutrients (77, 93). This is supported by the work of Arnon and co-workers (5, 6) who have shown that, since in nutrient solutions pH has very little effect upon the availability of the nutrients, varying the pH of the solution between 4 and 8 had no appreciable influence upon plant growth or upon the adsorption of magnesium, phosphorus, or nitrates by the plant. Calcium applications generally, but not always (82), increase the percent calcium in the plant, and usually decrease the other bases to some extent, although exceptions are common. The content of the

minor elements iron, copper, boron, and manganese in the plant are generally decreased, especially if the soil were originally acid. Liming seldom has much effect upon the amount of phosphorus in the plant, but lime with superphosphate often increases the percent of plant phosphorus more than either amendment alone (15). The nitrogen content of forage seems to be only slightly and inconsistently influenced by the application of lime (14).

Using magnesium carbonate in place of part of the calcium, or using dolomitic limestone, causes variations in plant composition similar to those that occur when calcium lime is used, except that the percent calcium is usually decreased while the percent magnesium is increased. In some cases, increases in phosphorus content have been observed with magnesium applications, so the theory has been proposed (94, 107) that magnesium is necessary for the proper metabolism of phosphorus. The work of Hunter (41) and others (17, 27, 76) did not support this theory, so this relationship is questionable.

Phosphorus fertilization generally increases phosphorus uptake by the plant, but it has a varying effect upon the calcium content. In field experiments in which superphosphate is generally used, this relationship is confused by the addition of calcium in the monocalcium phosphate and in the calcium sulfate which are present in normal superphosphate. In general, however, there seems to be no

correlation between phosphorus fertilization and the calcium content of the plant (17, 82, 87). The effects of phosphorus on the uptake of other cations are also usually minor, unless possibly for magnesium, as mentioned above. Variations in the nitrogen content of plants with phosphorus applications are quite inconsistent and depend upon many other factors. For instance, Allaway and Nelson (3) found that, on the average, applications of phosphorus increased the nitrogen content of alfalfa 0.16% (1.00% protein). Smith, et al (87) observed increased nitrogen uptake on one soil type, but not on another, while Blair and Prince (17) failed to obtain an increase in nitrogen content of alfalfa upon adding superphosphate. The very meager literature relating phosphorus fertilization to the uptake of minor elements shows no definite trends, with the possible exception that it may result in increased manganese uptake (15, 66).

Additions of potassium to the soil tend to increase potassium uptake by plants and to decrease the uptake of some of the other bases (25, 101). Potassium uptake seems to be related more to its supply in the soil than is the uptake of any other major plant nutrient (80). According to the work of some investigators (56, 72), the uptake of boron is stimulated by potassium applications. Iron uptake may also be increased (71), but information is lacking to make conclusions regarding the other minor elements. Deficiencies

of potassium in the soil often seriously interfere with nitrogen metabolism, increasing the amounts of ammonium, amides, and the basic amino acids, and decreasing the organic acids in the plant (14, 18, 34, 73, 87, 103). Such deficiencies seldom have a significant effect upon the percent of total nitrogen in the plant. Because of this interference in nitrogen metabolism, plants grown in soils low in potassium tend to contain higher concentrations of the protein derivatives, but are lower in carbonaceous materials. Therefore it is generally concluded that potassium fertilization tends to increase the carbohydrate content of the plant. Both Wall (103) and Eaton (34) found that, although potassium applications increased total carbohydrates in the plant initially, at higher rates of potassium fertilization the total carbohydrates began to decrease. This decrease was mainly in the content of reducing sugars, not starch (1, 14, 34). No generalities may be made as to the effects of potassium fertilization upon the phosphorus content of plants since the published results vary too widely. For example, Wall (103) observed an increase in the percent phosphorus; Albrecht (1) and Evans, et al (36) observed a decreased phosphorus content, while Smith, et al (87) and Beeson (15) found no significant variations.

EXPERIMENTAL METHODS

Greenhouse

General

This experiment was set up to study the effects of the application to the soil of varying amounts of calcium, magnesium, phosphorus, and potassium upon the dry weight yield and chemical composition of soybeans, oats, and alfalfa. These three crops were chosen because they are common agricultural crops grown in Michigan and are frequently used as feed for cattle. They have also been subjected to similar studies both at this and other agricultural experiment stations, so adequate information is available with which these data can be compared and supplemented. Calcium, magnesium, phosphorus, and potassium were chosen as the variable soil amendments since the effects of high and low levels of these elements are being used in the field for the production of the cattle feed used in the nutrition project previously mentioned. Since adequate nitrogen and minor nutrients are supplied in the field, these were not studied in this experiment. There was evidence that, in the field, no conditions of extreme nutrient unbalance existed, but rather, that the nutrients were in proper balance at both high and low levels of fertility. For this reason, this greenhouse study was deemed necessary in order to study the effects of the various unbalanced

conditions of soil fertility upon plant composition.

Seventy treatments were employed in the greenhouse, each replicated four times, making a total of 280 one-gallon pots used in the experiment. The soil, a Fox sandy loam, was adjusted to pH levels of 4.7 (original pH), 5.8, 6.3, and 6.8 using calcium carbonate in one series and a mixture of 75% by weight calcium carbonate-25% magnesium carbonate in a second series. Thus there were seven lime treatments in all; the original soil plus the three higher pH levels with both liming materials. Mono-calcium phosphate, $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$, was added to the soil at three rates, giving four phosphorus levels of 13 (original soil), 30, 60, and 90 pounds per acre of available phosphorus by the Spurway reserve test. Likewise, four levels of potassium were maintained with potassium chloride; 60 (original soil), 100, 200, and 300 pounds per acre of available potassium by the Spurway test. An adequate supply of all other nutrients was maintained. Nitrogen was added in the forms of NaNO_3 and NH_4NO_3 , 50% of the nitrogen coming from each source. Anionic and cationic sources were used in order to reduce as much as possible the effects of nitrogen on the cation-anion ratio in nutrient uptake by the plants. All chemicals used were C.P. grade. The pH, level of available phosphorus, and level of available potassium used for each of the seventy soil treatments are given in Table I.

TABLE I

Soil pH Levels, Available Phosphorus, and Available Potassium Maintained in the Seventy Soil Treatments

Treatment ¹	Soil pH	Type of Lime	Available P (lbs/acre)	Available K (lbs/acre)
I-0	4.7	---	13	60
II-0	5.8	Ca	13	60
III-0	6.3	Ca	13	60
IV-0	6.8	Ca	13	60
V-0	5.8	Ca-Mg	13	60
VI-0	6.3	Ca-Mg	13	60
VII-0	6.8	Ca-Mg	13	60
I-A1	4.7	---	30	100
II-A1	5.8	Ca	30	100
III-A1	6.3	Ca	30	100
IV-A1	6.8	Ca	30	100
V-A1	5.8	Ca-Mg	30	100
VI-A1	6.3	Ca-Mg	30	100
VII-A1	6.8	Ca-Mg	30	100
I-A2	4.7	---	30	200
II-A2	5.8	Ca	30	200
III-A2	6.3	Ca	30	200
IV-A2	6.8	Ca	30	200
V-A2	5.8	Ca-Mg	30	200
VI-A2	6.3	Ca-Mg	30	200
VII-A2	6.8	Ca-Mg	30	200

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TABLE I (continued)

Treatment	Soil pH	Type of Lime	Available P (lbs/acre)	Available K (lbs/acre)
I-A3	4.7	---	30	300
II-A3	5.8	Ca	30	300
III-A3	6.3	Ca	30	300
IV-A3	6.8	Ca	30	300
V-A3	5.8	Ca-Mg	30	300
VI-A3	6.3	Ca-Mg	30	300
VII-A3	6.8	Ca-Mg	30	300
I-B1	4.7	---	60	100
II-B1	5.8	Ca	60	100
III-B1	6.3	Ca	60	100
IV-B1	6.8	Ca	60	100
V-B1	5.8	Ca-Mg	60	100
VI-B1	6.3	Ca-Mg	60	100
VII-B1	6.8	Ca-Mg	60	100
I-B2	4.7	---	60	200
II-B2	5.8	Ca	60	200
III-B2	6.3	Ca	60	200
IV-B2	6.8	Ca	60	200
V-B2	5.8	Ca-Mg	60	200
VI-B2	6.3	Ca-Mg	60	200
VII-B2	6.8	Ca-Mg	60	200
I-B3	4.7	---	60	300

TABLE I. (continued)

Treatment	Soil pH	Type of Lime	Available P (lbs/acre)	Available K (lbs/acre)
II-B3	5.8	Ca	60	300
III-B3	6.3	Ca	60	300
IV-B3	6.8	Ca	60	300
V-B3	5.8	Ca-Mg	60	300
VI-B3	6.3	Ca-Mg	60	300
VII-B3	6.8	Ca-Mg	60	300
I-C1	4.7	---	90	100
II-C1	5.8	Ca	90	100
III-C1	6.3	Ca	90	100
IV-C1	6.8	Ca	90	100
V-C1	5.8	Ca-Mg	90	100
VI-C1	6.3	Ca-Mg	90	100
VII-C1	6.8	Ca-Mg	90	100
I-C2	4.7	---	90	200
II-C2	5.8	Ca	90	200
III-C2	6.3	Ca	90	200
IV-C2	6.8	Ca	90	200
V-C2	5.8	Ca-Mg	90	200
VI-C2	6.3	Ca-Mg	90	200
VII-C2	6.8	Ca-Mg	90	200
I-C3	4.7	---	90	300

TABLE I. (continued)

Treatment	Soil pH	Type of Lime	Available P (lbs/acre)	Available K (lbs/acre)
II-C3	5.8	Ca	90	300
III-C3	6.3	Ca	90	300
IV-C3	6.8	Ca	90	300
V-C3	5.8	Ca-Mg	90	300
VI-C3	6.3	Ca-Mg	90	300
VII-C3	6.8	Ca-Mg	90	300

¹Key to above treatments:

Lime: I = pH 4.7; II, III, and IV = pH 5.8, 6.3, 6.8 with CaCO_3 ; V, VI, and VII = pH 5.8, 6.3, and 6.8 with Ca-MgCO_3 .

Phosphorus: 0 = 13 lbs/acre available P; A = 30 lbs/acre; B = 60 lbs/acre; C = 90 lbs/acre

Potassium: 0 = 60 lbs/acre available K; 1 = 100 lbs/acre; 2 = 200 lbs/acre; 3 = 300 lbs/acre

The soil was screened through a 4-mesh sieve and placed in one-gallon pots, 4200 grams in each. The required amounts of liming materials were thoroughly mixed with the soil in each pot, using a mechanical mixer. Distilled water was then added to each pot to maintain the soil at the moisture equivalent, and the soils were covered and incubated for two weeks to allow the liming material time in which to react. The pots were arranged in a completely random manner within each of the four replicates. Two large rolling tables were used for each replicate. Thus, the tables could be turned around and moved at weekly intervals to lessen any bias that could be introduced through a favored location on the table (as closer to the heating pipes, stronger light, etc.). During the winter, daylight was supplemented with artificial overhead lighting so that the plants received 14 to 16 hours of light daily.

Soybean Crop

During January 5 to 7, 1953, all pots were seeded to Hawkeye soybeans, ten seeds to a pot. At the same time, the phosphorus and potassium fertilizers were added in a band application. The seeds were planted with the soil moisture at about the moisture equivalent by stirring up the surface inch or so of the soil, then pressing an inverted flower pot (six-inch diameter) about one-half inch into the soil, leaving a ring in the surface of the soil in which

the seeds were then placed. The seeds were lightly covered with soil and very lightly packed. Fertilizers were applied in another ring made by pressing an inverted four-inch flower pot one inch into the soil. Thus, the fertilizer was placed in a band about one inch to the side and one inch below the seed.

Immediately after being seeded, the pots were covered with wrapping paper to reduce water evaporation from the soil surface. The paper was removed after the seedlings were well through the soil; usually in about a week. With this and the succeeding crops, it was found that the control of soil moisture was critical at this stage. Sufficient moisture and air had to be maintained in the surface inch or two of soil for almost a week until the seedlings emerged and began developing their first true leaves. By this time, the root system was usually well enough developed to remove moisture from greater depths, so surface evaporation became less important, and the formation of a crust over the soil as a result of watering was less detrimental. In order to maintain an adequate oxygen supply for the germinating seeds, the surface soil could not be too moist. Therefore, there was only a narrow range around the moisture equivalent in which the soil moisture could vary in the surface of this soil without seriously retarding germination. Difficulties arose if one attempted to add water to the

surface of this soil before the seedlings emerged because of its pronounced tendency to cake over and form a crust through which the seedlings emerged with difficulty.

Therefore, it was found from experience that germination was greatly improved if enough water was added several days prior to planting to bring the entire body of soil in the pot well above moisture equivalent. Since the surface dried the fastest, in a few days it was down to moisture equivalent while the soil below still held excess water. By planting the seeds at this time, they were able to germinate without difficulty because the surface soil was kept moist by the upward movement of the excess water, especially if the pot were covered so that the air above the soil was nearly saturated.

About two or three weeks after planting, when the seedlings were well established, they were thinned to five plants per pot. The plants that were pulled up were left on the surface of the pot (as were all weeds that were removed) in order not to remove any nutrients from the pot. The soils in the pots were maintained at approximately moisture equivalent by weighing periodically and adding distilled water accordingly, usually about every two or three days. Close observations were made for deficiency symptoms. Whenever they were suspected, tissue tests were made to confirm them. Photographs were taken of plants showing characteristic differences.

Nitrogen was twice added in solution, on February 6 when the plants were growing vigorously in the vegetative stage, and again on March 4 when they had begun to blossom. A mixture of NaNO_3 and NH_4NO_3 containing 50% of the nitrogen from each source was used each time at rates of 30 pounds of nitrogen per acre. The entire above ground parts of the plants were harvested March 27 to 29 when the pods were formed and had begun to fill. These samples were dried in an electric oven at $45\text{-}55^\circ \text{C}$, then weighed and ground in a Wiley mill. Aliquots of samples from each of the four replicates for each treatment were taken, composited, and delivered to the Agricultural Chemistry department for chemical analyses.

Oats crop

After the harvest of the soybean crop, when the soils were partially dry, that from the four pots in the same treatment was thoroughly mixed, and a fifty-gram sample was taken for soil tests and laboratory work. The soil representing each treatment was then divided equally and returned to the four pots. This method not only reduced the number of soil tests necessary from two hundred eighty to seventy, but it also insured more uniformity among the replicates for the next crop. After determining the amounts of lime and fertilizer required to raise the fertility levels of the soil to those used for the soybeans, the liming materials

were thoroughly mixed into each pot, the soils moistened, incubated for several weeks, and oats of the Eaton variety were seeded on June 29-30, 1953, in a manner similar to that described above with the soybeans. About two weeks after germination, the plants were thinned to nine plants per pot. Nitrogen fertilizers, equivalent to 20 pounds of nitrogen per acre were applied twice; at the tillering stage on July 17, and on August 3 when the plants had begun to head. Observations were made and pictures were taken of plants showing visual growth abnormalities. The plants were harvested at the dough stage. The harvest was spread over the period of August 19 to 24 in an attempt to harvest all plants at the same stage of maturity. As with the soybean crop, the plants were dried, weighed, ground, composited, and delivered for chemical analyses.

Alfalfa crop

Essentially the same procedure was followed for the alfalfa crop. Pots were seeded to Ranger alfalfa on December 17 to 18, 1953, and were thinned to seven plants per pot after the seedlings were established. No nitrogen was applied, and pictures were taken as warranted. The plants were harvested at one-fourth bloom stage (two blossoms per pot) during the period of March 17 to April 3. Some "no phosphorus" treatments produced plants that never bloomed. The plants were dried, weighed, ground, composited, and delivered for chemical analyses.

Laboratory

Methods of Characterizing the Soil

The soil used in this study was classified as Fox sandy loam. It was taken from the surface of Field #5, a depleted field, on the Flowers farm near Gull Lake, Michigan in September, 1952. This is the farm which produced the feed used in the American Dairy Association Nutrition Project (28). A mechanical analysis was made on this soil by the hydrometer method of Bouyoucos (20). Organic matter was determined by Robinson's method of treating the soil with 15% hydrogen peroxide and heating. The moisture equivalent was found by centrifuging the saturated soil for thirty minutes at a force 1,000 times that of gravity. Soil pH was determined potentiometrically with the Macbeth alternating current pH meter with glass electrode. The ammonium acetate procedure of Schollenberger and Simon (78) was used for the determination of the base exchange capacity of the soil. A spectrographic analysis of a 1:1 HCl extract of an ashed sample of the surface soil taken from the same plot in approximately the same location was also made.

Calibration of the Fertilizer and Lime Requirement

In this experiment it was desired to grow crops at three pH levels using both calcium carbonate and a 75% calcium carbonate-25% magnesium carbonate mixture, three levels

of available phosphorus, and three levels of available potassium, plus the controls. Therefore, it was necessary to determine the amounts of these soil amendments required to raise the field soil to the desired levels of: pH 5.8, 6.3, and 6.8; available phosphorus at 30, 60, and 90 pounds per acre; and available potassium at 100, 200, and 300 pounds per acre. In order to do this, 100 grams of screened soil was added to a series of 250 milliliter beakers in the laboratory, and the respective liming and fertilizing materials were added in increasing increments to these beakers, as proposed by Watson (104). After incubating the soils at optimum moisture for two weeks, soil samples were taken and soil tests for pH, available phosphorus, and available potassium were run by the Spurway reserve method (91). From these data, calibration curves of soil test results versus pounds per acre of amendment added were constructed from which the amounts of liming and fertilizing materials to be used for each treatment in the greenhouse pots were calculated. These same curves were used after the removal of each crop to calculate the amounts of soil amendments that the soil in each pot required in order to bring it back to the desired fertility levels prior to the planting of the next crop.

Soil Tests

All soil tests for available phosphorus, available

potassium, and pH were made according to the Spurway reserve method (91). Soil tests were run on the original field soil, on the soils used in the beakers for the construction of the fertilizing and liming calibration curves, and on screened samples from the greenhouse pots after harvesting each crop. Samples of the field soil were also subjected to determinations of available iron and manganese by the Spurway method. The nutrient deficiency symptoms of the growing plants were confirmed by use of the Spurway tissue tests.

Determination of Exchangeable Bases

The total millequivalents of each of the four principle soil bases, sodium, potassium, calcium, and magnesium, were determined for each of the seventy soil treatments, both before and after cropping. The percent saturation of the soil exchange complex by each base for each treatment was calculated. Since the phosphorus and potassium fertilizers were banded in the greenhouse pots, it was impossible to determine the base saturation of the soil before cropping using the greenhouse soil as a source of material. Therefore, the samples used before cropping came from the same beakers that were used in the laboratory as the source of the data required for the construction of the liming and fertilizing curves. Thus, the information obtained from the studies on the base status of the soil before cropping

and that obtained from the soil tests used in the calibration curves are directly comparable.

A ten-gram sample of the screened soil was leached with 180 milliliters of neutral normal ammonium acetate, and the total volume was brought up to 200 milliliters with more ammonium acetate. A fifty milliliter aliquot was removed for the determination of calcium and magnesium by the versenate method, and the remainder of the filtrate was saved for the determination of the other bases with the flame photometer. The method followed in the versenate titration was essentially that of Cheng and Bray (22), although several modifications were introduced. Originally it was desired to titrate calcium and magnesium together using F241 indicator, then to determine calcium alone with murexide indicator, in ammonium acetate. Following the procedure of Cheng and Bray, it was found that neither indicator would give a reliable endpoint in an ammonium acetate solution. Since F241 is the sodium salt of an organic acid, it was thought that its ionization may have been suppressed by the common ion effect of the sodium added in the sodium hydroxide required to bring the solution up to a pH of 10. In order to avoid this, concentrated ammonium hydroxide was substituted for sodium hydroxide, and reliable endpoints were obtained for the titration, as Table II indicates. Murexide indicator still failed to give a definite endpoint in ammonium acetate. Attempts to remove the calcium from

TABLE II

Standardization of Versenate

mg Mg*	ml Versenate	mg Mg/ ml Vers.	mg Ca*	ml Versenate	mg Ca/ ml Vers.
<u>(in NH₄OAc)</u>					
0.2	0.56	0.3571	0.5	1.10	0.4545
0.4	1.14	0.3509	1.0	2.20	0.4545
0.6	1.73	0.3468	1.5	3.31	0.4532
0.8	2.32	0.3449	2.0	4.46	0.4484
1.0	2.92	0.3425	3.0	6.70	0.4478
2.0	5.77	0.3466	4.0	8.95	0.4469
3.0	8.65	0.3468			
4.0	11.54	0.3466			
Ave. 0.347			Ave. 0.451		
<u>(in H₂O)</u>					
0.2	1.04	0.1923	0.5	0.98	0.5102
0.4	2.05	0.1951	1.0	1.96	0.5102
0.6	3.08	0.1948	1.5	2.95	0.5085
0.8	4.08	0.1961	2.0	3.94	0.5076
1.0	5.13	0.1941	2.5	5.00	0.5000
2.0	10.25	0.1951	4.0	7.95	0.5032
3.0	15.27	0.1964	6.0	11.94	0.5026
4.0	20.51	0.1961			

*Carbonate salts used

the ammonium acetate solution as a precipitate of citrate, phosphate, carbonate, or oxalate all failed. Therefore, it was necessary to determine calcium on the flame photometer, then calculate magnesium by difference.

The method employed for the determination of magnesium was as follows: ten milliliters of concentrated ammonium hydroxide was added to a fifty milliliter aliquot of the ammonium acetate filtrate in order to raise the pH to 10, seven drops of F241 indicator were added, and the solution was titrated with versenate standardized with calcium and magnesium salts dissolved in neutral normal ammonium acetate.

The method of Attoe and Truog (9) was used for the determination of potassium and sodium, except that normal ammonium acetate was used instead of two normal ammonium acetate and 0.2 normal magnesium acetate. Calcium was determined in a similar manner. The Beckman Model B flame photometer with acetylene gas was used. Since this instrument has a glass prism, it was impossible to determine magnesium by this method. Because of the low concentrations of sodium, and because of the several known interferences (especially from calcium), 25 ppm calcium, 10 ppm potassium, and 5 ppm magnesium were added to the sodium standards.

Chemical Analyses of the Plant Material

The chemical analyses of the plant material were made by the Agricultural Chemistry Department of the Michigan Experiment Station. The feedstuff analyses on ash, protein, nitrogen free extract, ether extract, and crude fiber were determined by the standard A.O.A.C. methods (8). Sodium and potassium were determined on the Perkin-Elmer Model 52-A flame photometer according to the method of Seay, et al (79). Spectrographic analyses for boron, phosphorus, iron, magnesium, manganese, calcium, and copper were made by the method that follows. A one gram sample of the plant material was ashed, taken up in 1:1 HCl, and LiCl was added as an internal standard. The solution was placed on the end of a polished carbon electrode, dried by infra-red light, and placed in the electrode holders. The electrodes were then sparked at 13 amperes, using four breaks per half second. This procedure was somewhat similar to that reported by Mathis (51). The values reported are the averages of duplicate determinations.

Statistical Analyses

An analysis of variance was made on the dry weight yields of each of the three crops, and the significance of each calculated F value was determined from Snedecor's tables (88). In order to simplify the analysis of variance

Table

Table 1. Summary of the data sets used in the study	
Dataset	Description
Dataset 1	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.
Dataset 2	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.
Dataset 3	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.
Dataset 4	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.
Dataset 5	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.
Dataset 6	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.
Dataset 7	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.
Dataset 8	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.
Dataset 9	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.
Dataset 10	1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.

Figure 1: Results

Figure 1 shows the results of the experiments. The top row shows the results for the 1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features. The bottom row shows the results for the 1000 samples of 100 features each, generated by a Gaussian mixture model with 10 clusters and 100 features.

so that the results would be intelligible to those who do not possess a profound knowledge of statistical analyses, the "no treatment" pots were not included. Thus, the analysis of variance was made on the basis of a factorial of three pH levels x two types of lime x three phosphorus levels x three potassium levels, and four replications, giving a total of 215 degrees of freedom. Averages for the controls are also given.

To save time and money, the four replicates were composited for chemical analyses. Therefore, analyses of variance could not be used to determine significant differences between treatments. For this reason, the coefficient of likelihood (26) was calculated for the different series of treatments, and its significance was determined from the appropriate table of L values (26). The coefficient of correlation for the different comparisons was calculated by the formula given by Croxton and Cowden (26).

RESULTS

Properties Characterizing the Soil

The results obtained in the determination of the properties which characterize the soil are given in Table III. The values obtained for this soil were fairly typical of a Fox sandy loam. According to Stolzy (92), the predominate clay in this soil type is illite, although some kaolinite and montmorillonite were also detected. The determinations of soil pH, available phosphorus, available potassium, and total nitrogen showed that the soil was seriously depleted in available nutrients when it was brought to the greenhouse. This condition was desired for this experiment. The spectrographic analyses of the 1:1 hydrochloric acid extract of an ashed sample of this soil showed very little difference from the analyses of other plots in the field at the Flowers farm. The differences between the results for the fertilized and the unfertilized plots were small. Therefore, this method of analysis was questionable as a measure of the fertility status of the soil.

Fertilizer and Lime Requirements of the Soil

The amounts of fertilizers and liming materials required to raise the field soil to the desired fertility levels were determined from the calibration curves made by

TABLE III.

Some Physical and Chemical Properties Characterizing
the Soil Used in this Study

% Sand ¹ - - - - -	63.6	% Boron - - - - -	0.0044
% Silt ² - - - - -	25.2	% Phosphorus - - -	0.064
% Clay ³ - - - - -	11.2	% Iron - - - - -	0.069
% Organic Matter -	2.02	% Magnesium - - -	0.618
% Water at Moisture Equivalent - -	10.1	% Manganese - - -	0.085
Soil pH	4.7	% Calcium - - - -	0.32
Available Soil Phos- phorus, lb/acre	13	% Copper - - - -	0.00022
Available Soil Potas- sium, lb/acre -	60	% Nitrogen - - -	0.100
Cation Exchange Capa- city, m.e./100 gm.	4.07	Soil Type -	Fox sandy loam
		Type of Clay ⁴ -	Illitic

¹Over 50 u in size

²From 2 to 50 u in size

³Under 2 u in size

⁴L. Stolzy, Ph.D. Thesis, Michigan State College, 1954.

plotting soil test results against the pounds per acre of the soil amendments added to one hundred grams of soil in 250 milliliter beakers. These calibration curves for the determination of the amounts of liming materials, mono-calcium phosphate, and potassium chloride required for each of the seventy treatments are presented in Figures 1, 2, and 3 respectively. All points on the curves are averages of three determinations. The graph in Figure 1 shows that more calcium carbonate was required, especially at the higher pH values, to give a certain pH level than was required of the calcium-magnesium mixture. It is interesting to note that less than one and one-half tons per acre of liming material was required to raise the pH of this soil from 4.7 to 6.8, which indicates that the soil has a low buffering capacity.

The amount of phosphate fertilizer required to increase the level of available soil phosphorus to 90 pounds per acre was surprisingly large (Figure 2). This fact is particularly evident if the amount of monocalcium phosphate required is converted to the equivalent amount of superphosphate. Because this soil was highly acid, it is possible that some of the added phosphorus was fixed as iron and aluminum phosphates.

The quantity of potassium chloride required was not unduly large, as Figure 3 indicates. The data represented

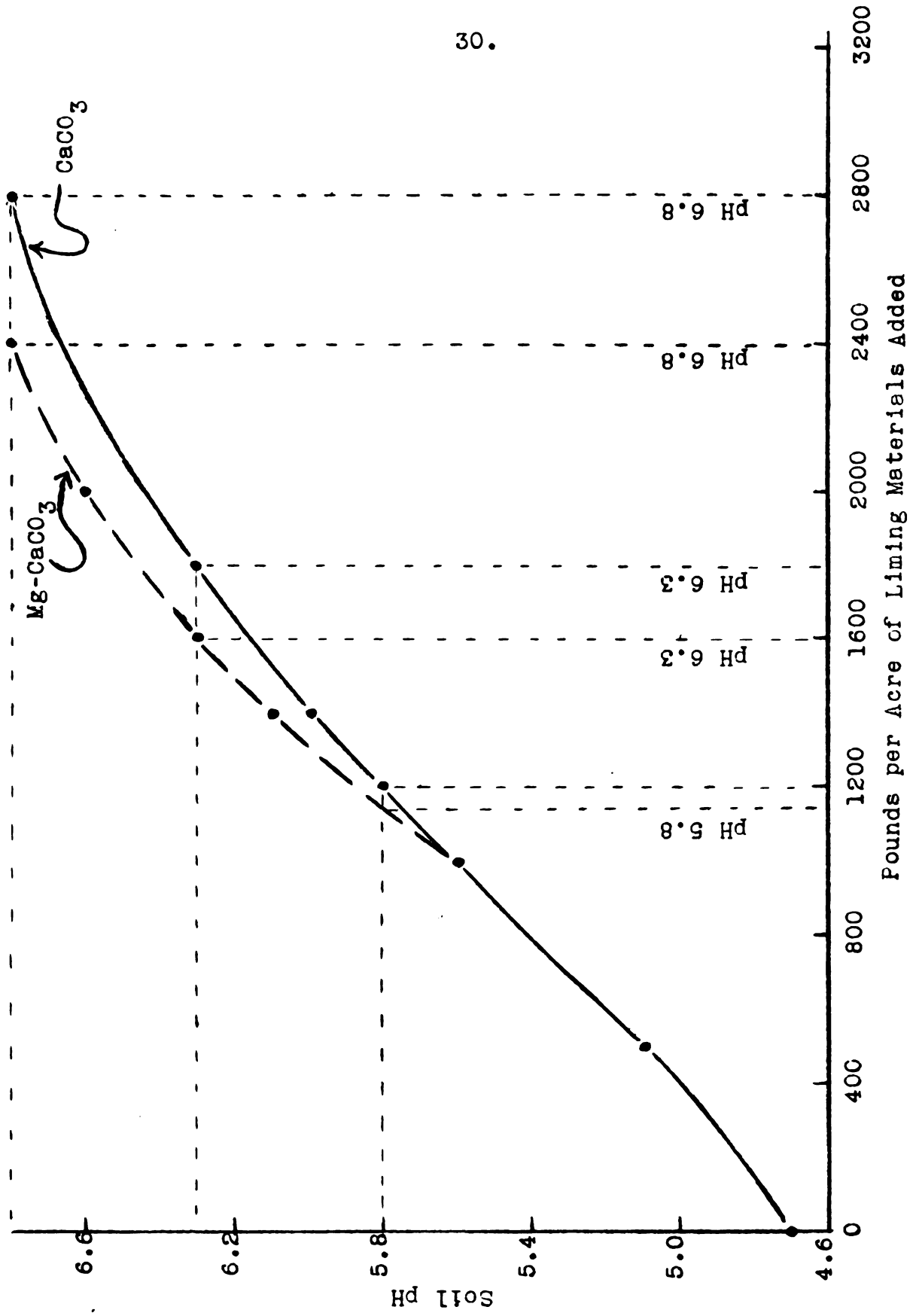


Figure 1. Effect of Liming Materials on Soil pH.

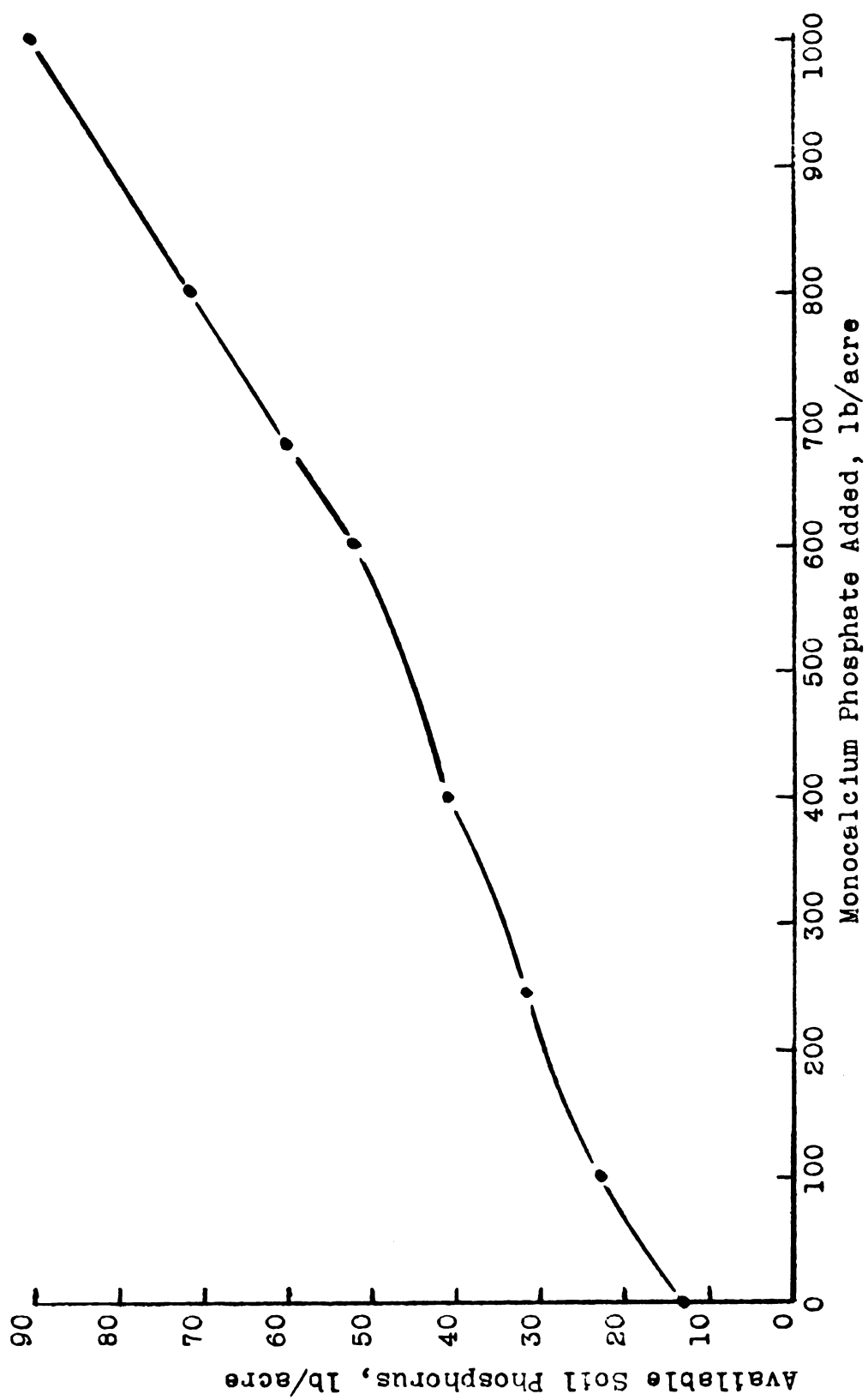


Figure 2. Effect of Phosphate Fertilizer on Available Soil Phosphorus.

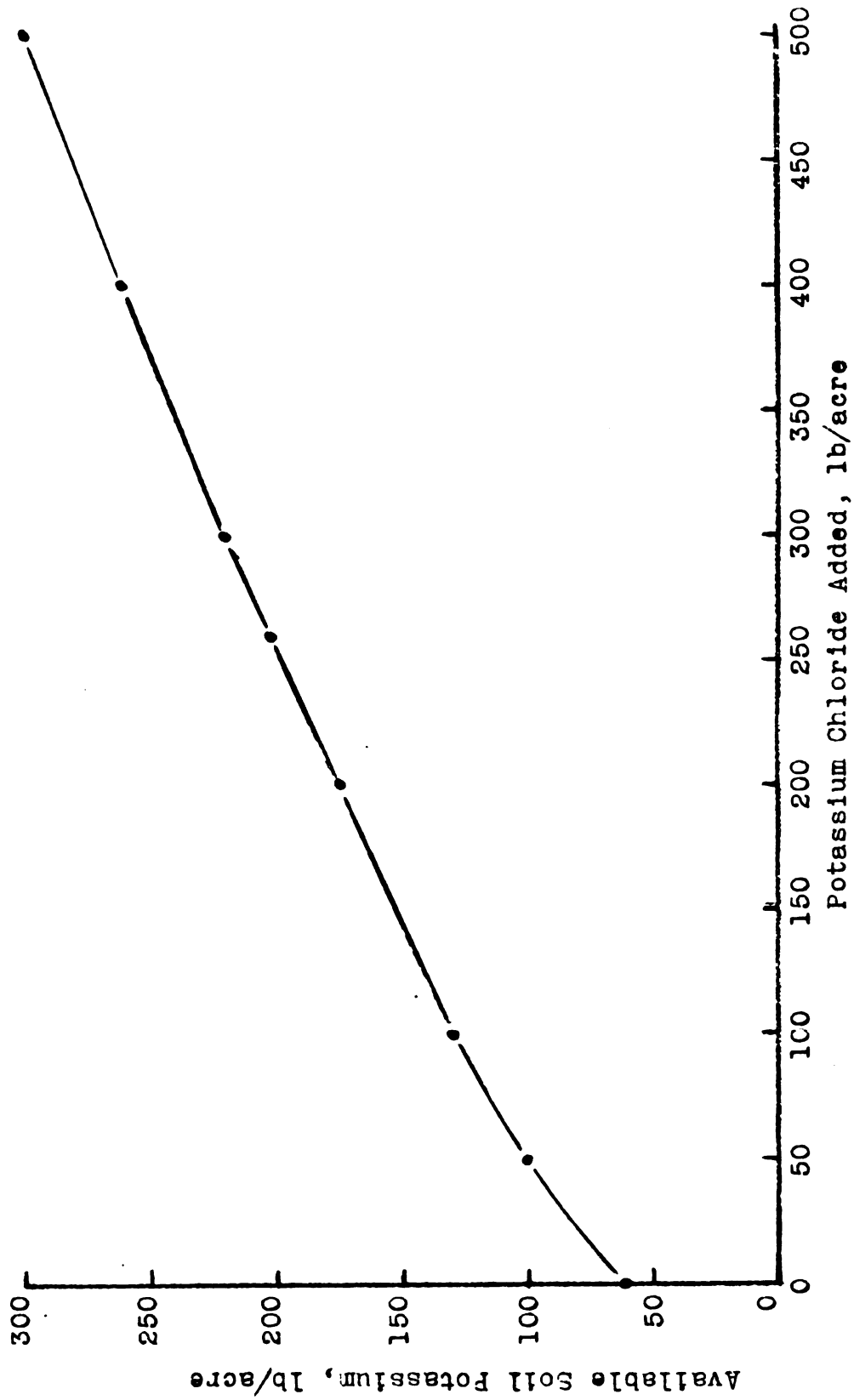


Figure 3. Effect of Potassium Fertilization upon Available Soil Potassium.

by this graph suggest that there was hardly any fixation of the added potassium, except possibly at low values, since available potassium increased almost pound for pound with that added.

Results of Soil Tests

The amounts of lime and fertilizers required for each of the seventy soil treatments were calculated from the calibration curves (Figures 1, 2, and 3) with the aid of the soil test results made after the harvest of each crop. The fact that the soil pH decreased greatly with the growth of only one crop, in several cases over one full pH unit, indicates further the low buffering capacity of the soil. Large decreases also occurred in the pounds per acre of available phosphorus and potassium. The decreases in pH were not quite so large after the removal of the oats crop as they were after the removal of the soybean crop. This might have been expected since soybeans tend to take up more calcium than do oats. No soil tests were made after the alfalfa crop was harvested.

In determining the amounts of fertilizer required after the removal of a crop, it frequently happened that the soil test was below that of the original soil. In such cases, the fertilizer requirement was calculated by extrapolating to the left. Thus, those values may not have been so reliable as the ones that were calculated without

extrapolation, but the errors were probably minor because of the very small amounts of fertilizers involved in that region of the curve.

Exchangeable Base Status for Each Soil Treatment

The results of the exchangeable base determinations of the soil for each of the seventy soil treatments before cropping are presented in Table IV. The percentages of calcium, magnesium, and potassium saturation of the soil tended to increase regularly as more of these cations were added to the soil. Since calcium constituted almost two-thirds of the cations in the soil, variations in the total percent saturation were determined primarily by variations in the amount of calcium present, and to a lesser degree by variations in the amount of magnesium present. The percent potassium saturation was so low, even at high potassium levels (level "3"), that variations in potassium treatments seemed to have no significant effects on the percent of total base saturation.

The degree of base saturation of the soil at some of the higher pH levels was over 100 percent, which is interpreted to mean that free salts were present in the soils of these treatments, even though the reaction of the soil was below the theoretical neutral point. However, this is not uncommon for a soil with such a low exchange capacity (23).

TABLE IV
Base Status for the Seventy Soil Treatments
Before Cropping*

Treatment	Ca	Mg	K	Na	Total
I-0	21	7	2.7	0.0	31
II-0	56	10	2.7	0.0	69
III-0	72	10	2.7	0.0	85
IV-0	98	12	2.7	0.5	113
V-0	38	23	2.7	0.0	65
VI-0	46	26	2.9	0.5	75
VII-0	62	40	2.7	9.1	114
I-A1	19	13	4.2	0.0	36
II-A1	41	29	4.2	0.0	74
III-A1	72	13	4.2	0.0	89
IV-A1	84	7	4.2	0.0	95
V-A1	41	27	4.2	0.0	72
VI-A1	53	27	4.2	0.7	85
VII-A1	71	29	3.9	3.9	106
I-A2	21	13	7.6	0.0	42
II-A2	53	13	6.4	0.0	73
III-A2	65	10	6.9	0.5	83
IV-A2	87	9	6.2	0.5	103
V-A2	41	19	6.4	0.0	66
VI-A2	46	21	5.7	0.7	74

*As percent saturation of total base exchange capacity

TABLE IV (continued)

Treatment	Ca	Mg	K	Na	Total
VII-A2	71	30	6.9	3.9	109
I-A3	21	14	10.3	0.0	46
II-A3	53	15	11.0	0.0	79
III-A3	56	10	10.5	0.0	77
IV-A3	89	6	11.0	0.0	106
V-A3	41	25	9.8	0.0	75
VI-A3	53	27	11.0	0.5	92
VII-A3	56	30	10.3	5.4	102
I-B1	24	10	3.4	0.0	38
II-B1	49	11	3.4	0.0	64
III-B1	56	38	3.4	0.0	97
IV-B1	84	21	3.9	5.4	113
V-B1	44	21	3.9	0.0	68
VI-B1	49	30	3.9	0.7	83
VII-B1	59	31	3.9	4.2	98
I-B2	24	10	6.2	0.0	40
II-B2	59	15	6.6	0.0	80
III-B2	75	10	6.6	0.0	91
IV-B2	89	10	6.2	0.0	106
V-B2	44	20	6.4	0.0	70
VI-B2	56	22	6.6	6.6	92
VII-B2	59	32	7.4	4.2	102
I-B3	24	12	10.3	0.0	47
II-B3	53	13	11.0	0.0	78
III-B3	71	13	10.5	0.0	92
IV-B3	80	5	10.5	0.0	96

TABLE IV (continued)

Treatment	Ca	Mg	K	Na	Total
V-B3	49	28	11.3	1.7	84
VI-B3	53	26	10.3	4.2	94
VII-B3	59	33	11.3	4.2	108
I-C1	29	5	4.2	0.0	38
II-C1	56	12	3.4	0.0	71
III-C1	65	10	3.2	0.0	78
IV-C1	108	5	3.9	0.5	117
V-C1	41	20	3.4	0.0	64
VI-C1	56	23	4.7	3.7	87
VII-C1	68	23	3.9	4.2	100
I-C2	26	15	6.9	0.0	48
II-C2	56	14	6.4	0.5	77
III-C2	68	15	6.4	0.0	90
IV-C2	92	9	6.4	0.0	108
V-C2	44	20	6.4	0.0	70
VI-C2	62	24	6.9	4.2	97
VII-C2	75	27	6.6	4.9	114
I-C3	26	17	10.5	0.0	53
II-C3	53	13	10.5	0.5	77
III-C3	72	13	11.8	0.7	98
IV-C3	78	11	10.3	0.0	100
V-C3	46	7	10.3	0.0	81
VI-C3	49	29	10.5	4.2	93
VII-C3	59	32	10.5	4.9	107

The percentage of the cation exchange capacity saturated with sodium varied unexpectedly for some soil treatments. The data in Table IV indicate that, in almost all cases, the percent sodium saturation increased with the percent magnesium saturation. Originally, the sodium standards used in the flame determinations contained no magnesium salts, so it was thought that magnesium might be exerting an additive interference upon the sodium readings. However, upon adding magnesium carbonate to the standards, no change occurred in the percent transmittancy readings or the standard curve for sodium, so the possibility of magnesium interference was eliminated. Since sodium had not been added to this soil in the laboratory, nor for some time in the field to the author's knowledge, and since the readings for most other treatments indicated its virtual absence, these high values probably do not represent the actual sodium concentrations present. Sodium determinations on soil samples taken from the greenhouse pots failed to exhibit this increase in concentration with the percent magnesium saturation of the soil.

Since the cation status of a soil is often expressed in the form of ratios of the various bases (13, 41, 63, 81, 101), the ratios of the millequivalents of Ca/K, Ca and Mg/K, and Ca/Mg were calculated for each of these seventy soil treatments. These values are listed in Table V. Their influence upon plant composition and growth will be discussed

TABLE V

Cation Ratios for the Seventy Soil Treatments

Treat- ment	Ca/K	$\frac{\text{Ca\&Mg}}{\text{K}}$	Ca/Mg	Treat- ment	Ca/K	$\frac{\text{Ca\&Mg}}{\text{K}}$	Ca/Mg
I-0	7.73	10.45	2.83	VII-A2	9.93	14.29	2.28
II-0	20.73	24.55	5.43	I-A3	2.02	3.35	1.47
III-0	26.55	30.36	6.95	II-A3	4.78	6.16	3.47
IV-0	36.36	40.73	8.33	III-A3	5.30	6.28	5.53
V-0	14.09	23.00	1.69	IV-A3	8.09	8.62	15.15
VI-0	15.67	24.33	1.81	V-A3	4.15	6.65	1.66
VII-0	23.00	34.85	1.54	VI-A3	4.78	7.23	1.95
I-A1	4.53	7.59	1.48	VII-A3	5.43	8.34	1.87
II-A1	9.76	16.59	1.43	I-B1	6.92	9.93	2.31
III-A1	17.18	20.35	5.41	II-B1	14.38	17.57	4.35
IV-A1	20.00	21.53	9.73	III-B1	21.22	26.51	4.05
V-A1	9.77	16.12	1.54	IV-B1	12.50	20.00	1.67
VI-A1	12.65	19.12	1.95	V-B1	11.05	16.31	2.11
VII-A1	17.38	24.90	2.32	VI-B1	12.50	20.00	1.67
I-A2	2.74	4.48	1.57	VII-B1	15.00	22.88	1.90
II-A2	8.27	13.46	3.98	I-B2	3.88	5.56	2.31
III-A2	9.43	10.93	6.29	II-B2	8.89	11.10	4.00
IV-A2	14.12	15.64	9.03	III-B2	11.21	12.70	7.58
V-A2	6.38	9.35	2.13	IV-B2	14.55	16.21	8.67
VI-A2	8.18	11.91	2.19	V-B2	6.81	9.88	2.21

TABLE V (continued)

Treat- ment	Ca/K	<u>Ca&Mg</u> K	Ca/Mg	Treat- ment	Ca/K	<u>Ca&Mg</u> K	Ca/Mg
VI-B2	8.44	11.77	2.54	III-C3	6.08	7.22	5.41
VII-B2	8.00	12.32	1.85	IV-C3	7.50	8.60	6.85
I-B3	2.31	3.50	1.94	V-C3	4.38	5.03	6.72
II-B3	4.78	5.98	3.98	VI-C3	4.65	7.40	1.69
III-B3	6.47	7.72	5.15	VII-C3	5.58	8.65	1.82
IV-B3	7.58	8.10	14.81	Averages for the lime treatments are as follows:			
V-B3	4.35	6.41	2.22				
VI-B3	5.12	7.64	2.03	I	4.34	6.28	2.30
VII-B3	5.22	8.18	1.76	II	10.16	13.24	3.93
I-C1	6.83	8.01	5.80	III	12.95	15.93	5.49
II-C1	16.28	19.71	4.75	IV	17.13	19.05	10.84
III-C1	20.30	23.37	6.61	V	7.98	11.92	2.45
IV-C1	27.36	28.62	21.89	VI	9.30	13.87	2.10
V-C1	11.85	17.56	2.08	VII	11.82	17.29	2.11
VI-C1	12.00	16.83	2.48	Averages for phosphorus treatments:			
VII-C1	17.37	23.10	3.02				
I-C2	3.79	5.93	1.77	0	20.59	26.89	4.08
II-C2	8.77	11.00	3.93	A	8.80	10.52	3.93
III-C2	10.69	13.06	4.49	B	8.28	12.73	3.76
IV-C2	14.50	15.95	9.92	C	10.14	12.86	4.87
V-C2	6.81	9.96	2.16	Averages for potassium treatments:			
VI-C2	9.04	12.42	2.64				
VII-C2	11.33	15.38	2.78	0	20.59	26.89	4.08
I-C3	2.47	4.03	1.56	1	14.32	20.09	4.21
II-C3	5.00	6.26	3.99	2	8.33	11.59	4.06
				3	5.05	6.73	4.25

later, but it is interesting to note a few observations at this point. The Ca/Mg ratios of the soils receiving magnesium (treatments V, VI, and VII) were generally fairly constant regardless of the soil pH value. The Ca/K ratios varied widely, from less than four to over twenty-five. In New Jersey soils, Bear and Toth (13) regarded a Ca/K ratio of 13 as ideal ratio for the growth of alfalfa.

It may be of interest to compare the soil test results with the base status determinations since they represent two different methods for measuring the nutrient supply of a soil. This was done in the graph in Figure 4 where the average percent base saturation of calcium plus magnesium for each pH level was plotted against the soil pH. A similar graph of average percent potassium saturation versus pounds per acre of available potassium is presented in Figure 5. It may be observed that these curves were generally linear, except at the extremes. This result is somewhat surprising because of the fact that two cations (H^+ and NH_4^+ in this case) seldom have the same effect upon the activity or availability of a third cation over such a wide range of concentrations. This phenomenon, and its relation to plant nutrition, will be discussed to a greater length in another part of this thesis.

Although the data reported in Table IV were designated as the base status of the soil before cropping, they do not

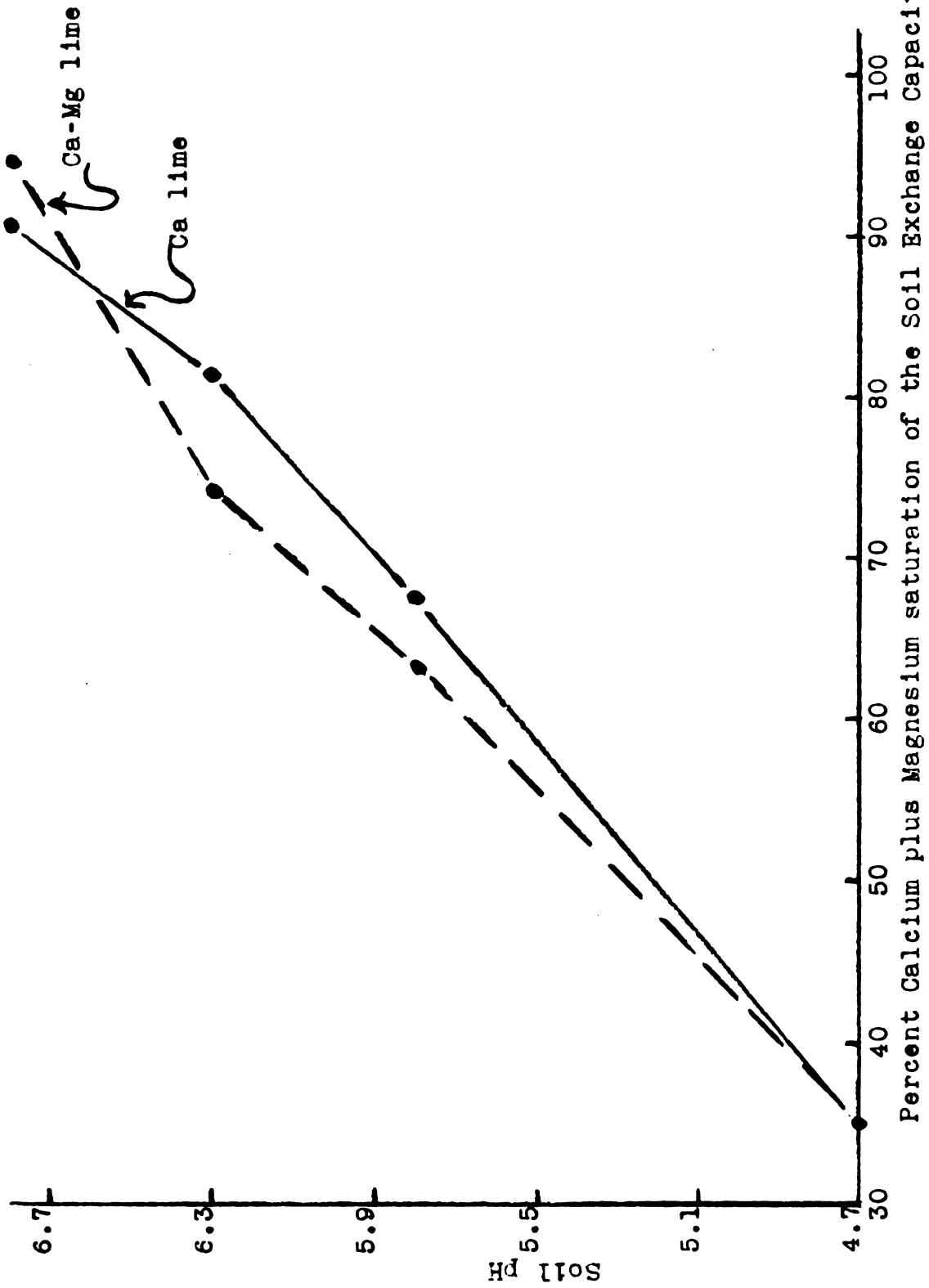


Figure 4. Effect of Percent Calcium plus Magnesium Saturation of the Soil Upon Soil pH.

1

2

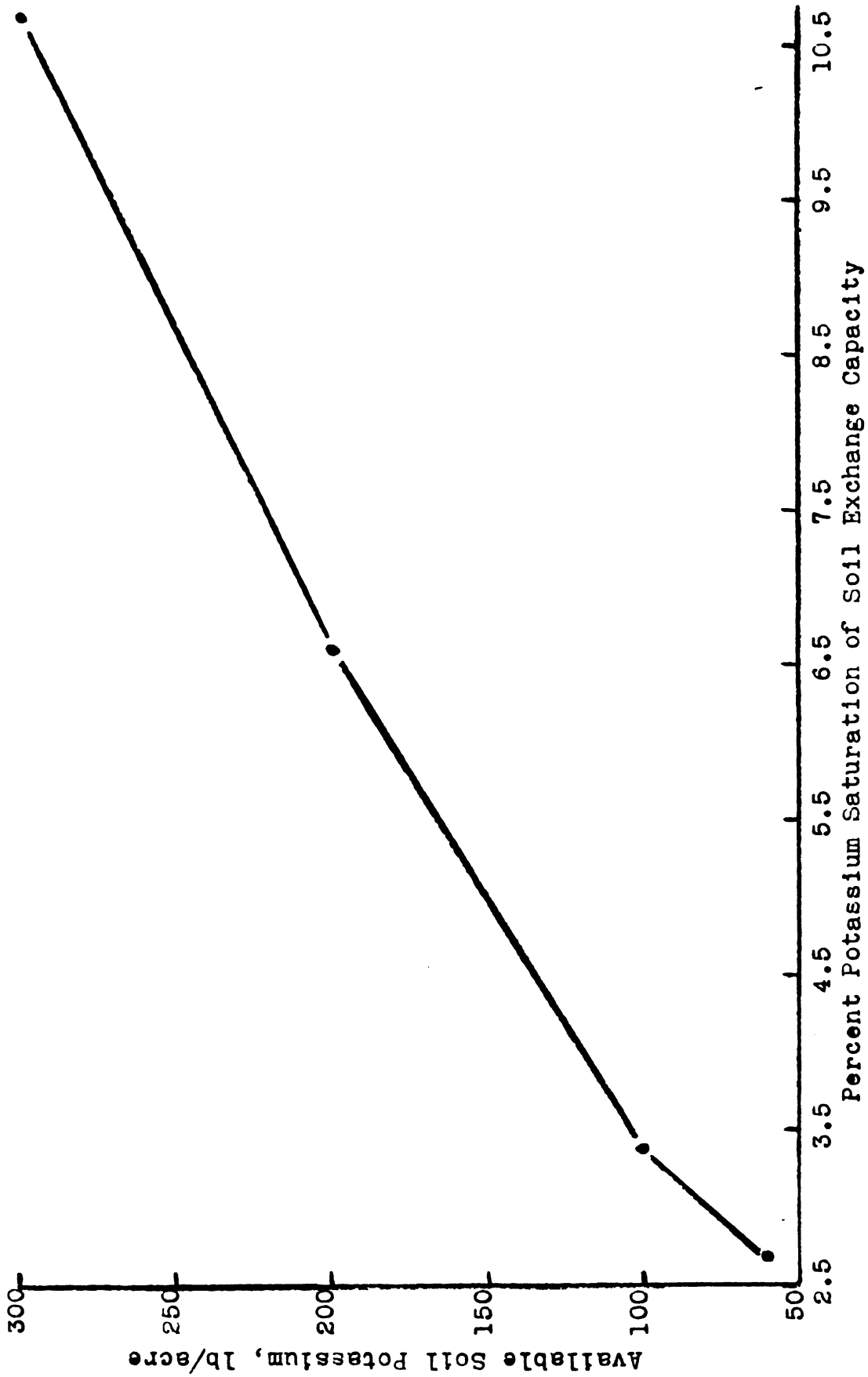


Figure 5. Relation of Percent Potassium Saturation of the Soil to Available Soil Potassium.

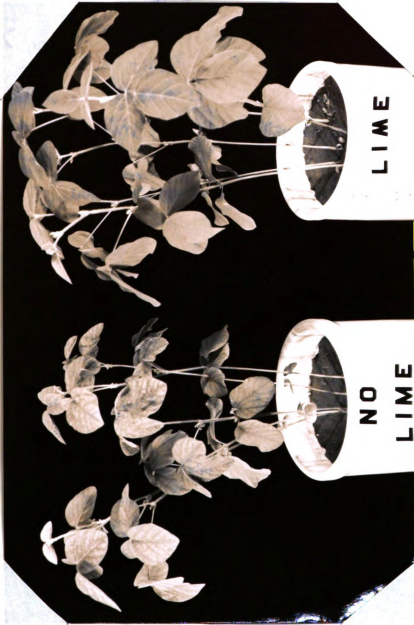
exactly represent the base status of the soils used in the greenhouse because the phosphorus and potassium fertilizers were banded in the greenhouse pots and were added in solution to the laboratory soils from which these data were obtained. However, since the degree of potassium saturation was so low that it hardly affected the total percent base saturation, this difference is probably negligible.

Observations and Data on Growth and Yield

Soybeans

Soybean plants which were grown at a soil pH of 4.7 began to show calcium deficiency symptoms when they were about six weeks old. This was indicated by a yellow mottling between the veins on the younger (upper) leaves. The pattern illustrated by Figure 6 was confirmed by tissue tests.

The plants exhibiting calcium deficiencies retained their cotyledons in a green condition throughout the entire growing period, whereas they were dropped from the other plants within a few weeks from emergence. The significance of this observation is not known. It was probably because a lack of calcium retarded the formation of new tissue (21), including possible secondary growth, thus eliminating the formation of an abscission layer of cells by the cambium at the base of the cotyledons.



a. Calcium deficiency on soybeans.

Figure 6. Pictures of soybean growth resulting from different soil treatments.

45a.



b. Magnesium deficiency on soybeans



c. Potassium deficiency on soybeans

Figure 6. (continued)

When the plants were 8 to 10 weeks old, potassium and magnesium deficiency symptoms began to appear on those plants grown in pots receiving low quantities of these materials. These symptoms were not so specific as were the calcium deficiency symptoms. The magnesium deficiency seemed to be slightly more severe in those cases where the soil had received low magnesium treatments accompanied by high potassium treatments. This was undoubtedly due to the antagonistic effect potassium has upon the uptake of other cations. The magnesium deficiencies became more apparent when the plants began to form pods, indicating that magnesium was being withdrawn from the older lower leaves and transferred to the reproductive parts. Pictures of the potassium and magnesium deficient plants are also presented in Figure 6.

Within a few weeks after emergence, the plants growing in soil with a pH of 4.7 (treatment I) were much smaller than the other plants. The differences which existed as a result of the other pH levels were not great enough to be visible. Also, it was impossible to distinguish between the different levels of available phosphorus and potassium by observing the size of the plants.

The plants were harvested when the pods had filled, since this corresponded to the stage of maturity at which soybeans are harvested in the field when they are used as hay. After drying, the plant samples were weighed and

the data analyzed by analysis of variance. In order to simplify this analysis of variance, the "no lime", "no phosphorus", and "no potassium" treatments (treatments I and O) were omitted. Thus the analysis of variance was a straight factorial (Table VI).

The smallest phosphorus application markedly increased the yield of soybeans, as shown by Figure 8, but quantities sufficient to raise the soil test above 30 pounds per acre did not cause further increases in yield. The PK interaction also was not significant. Likewise, the interaction between type of lime and soil potassium lacked significance, possibly due to antagonistic effects that one soil cation may have had upon the other. The type of lime was significant at only the 5% level, while all other treatments and interactions were highly significant.

Graphs of the average dry weight yields of soybeans for the seven lime treatments, four phosphorus treatments, and four potassium treatments are presented in Figures 7, 8, and 9. A steady increase in yield occurred with an increase in soil pH. In most cases, the mixed lime gave higher yields than did the calcium lime. This was expected since the plants of some treatments receiving no magnesium showed signs of magnesium deficiency. In all cases, highest yields were obtained at pH 6.8. According to the analysis of variance, these increases were significant.

TABLE VI

Analysis of Variance of Soybean Weights

Source	Degrees of Freedom	F Values
Total	215	--
Replications	3	5.63**
Treatments	53	3.26**
Type of Lime	1	5.40*
pH Level	2	21.13**
Type of Lime x pH Level	2	8.03**
Phosphorus Level	2	2.44
Type of Lime x Phosphorus Level	2	37.68**
pH Level x Phosphorus Level	4	23.50**
Type of Lime x pH Level x Phosphorus	4	30.72**
Potassium Level	2	13.50**
Type of Lime x Potassium Level	2	0.99
pH Level x Potassium Level	4	4.84**
Type of Lime x pH Level x Potassium	4	10.38**
Phosphorus Level x Potassium Level	4	2.24
Type of Lime x Phosphorus Level x Potassium Level	4	4.18**
pH Level x Phosphorus Level x Potassium Level	8	98.38**
Type of Lime x pH Level x Phosphorus Level x Potassium Level	8	11.83**
Error	159	--

* Significant at 5% level

**Significant at 1% level

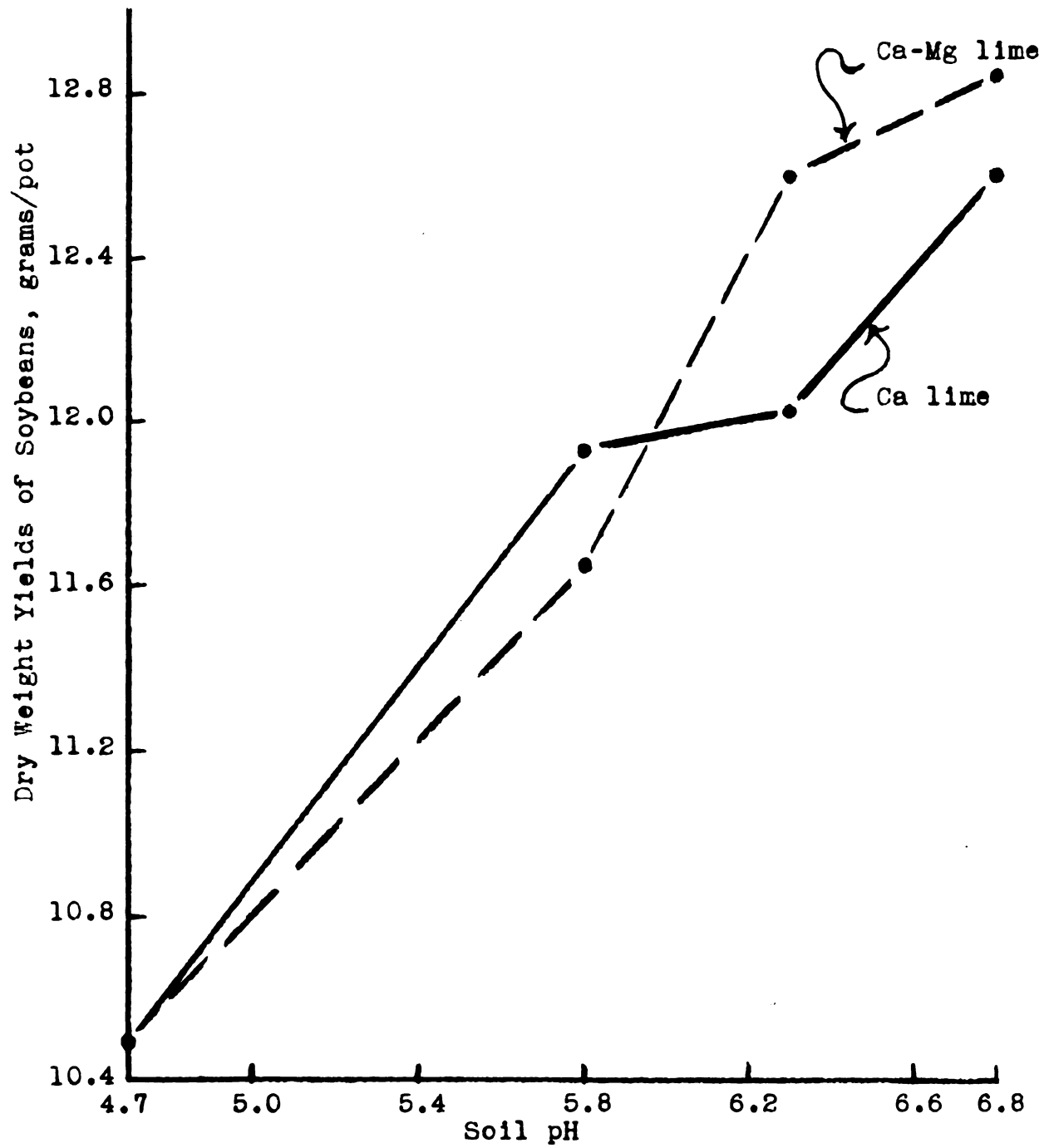


Figure 7. Effect of Soil pH upon Dry Weight Yields of Soybeans.

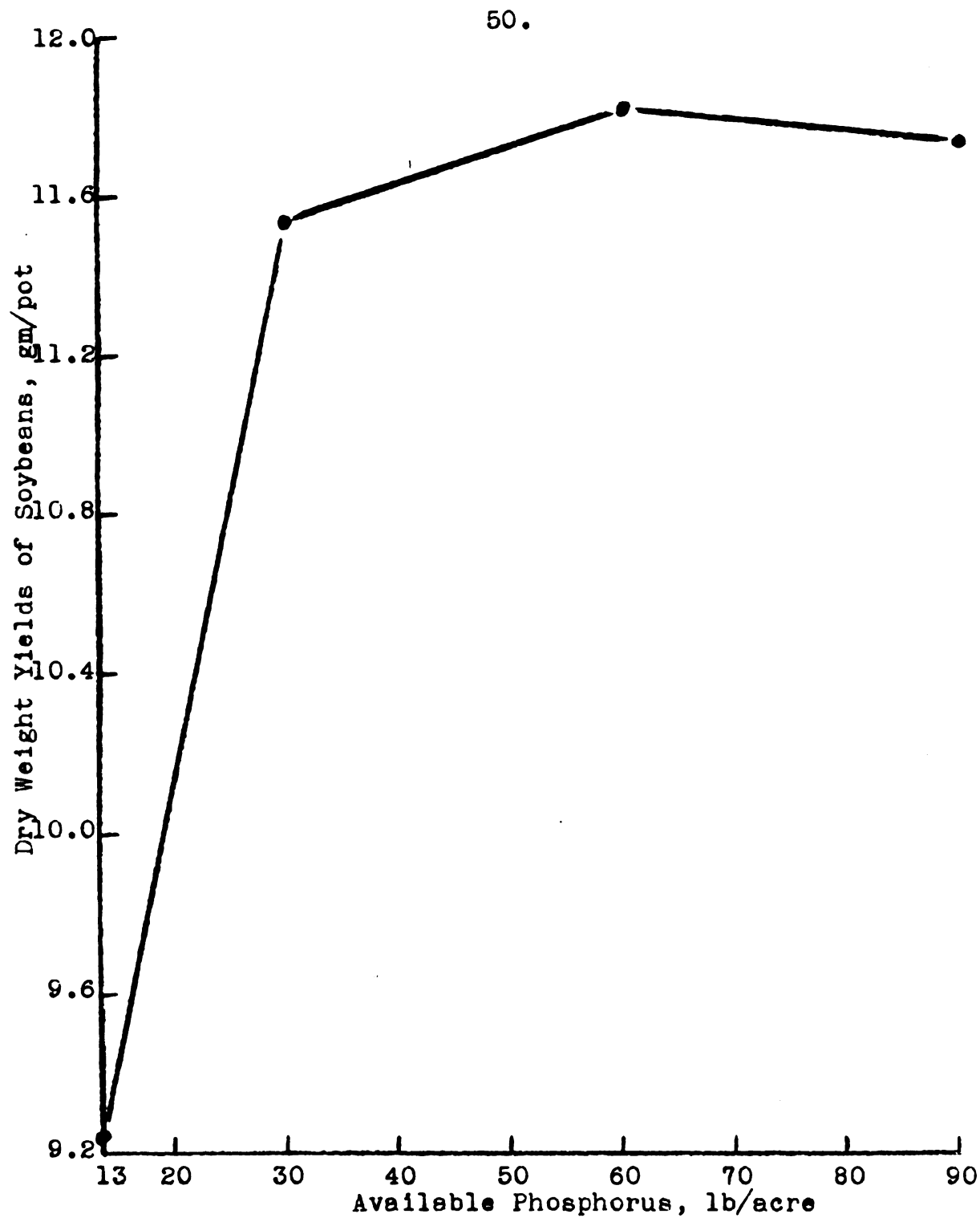


Figure 8. Effect of Available Soil Phosphorus upon Dry Weight Yields of Soybeans.

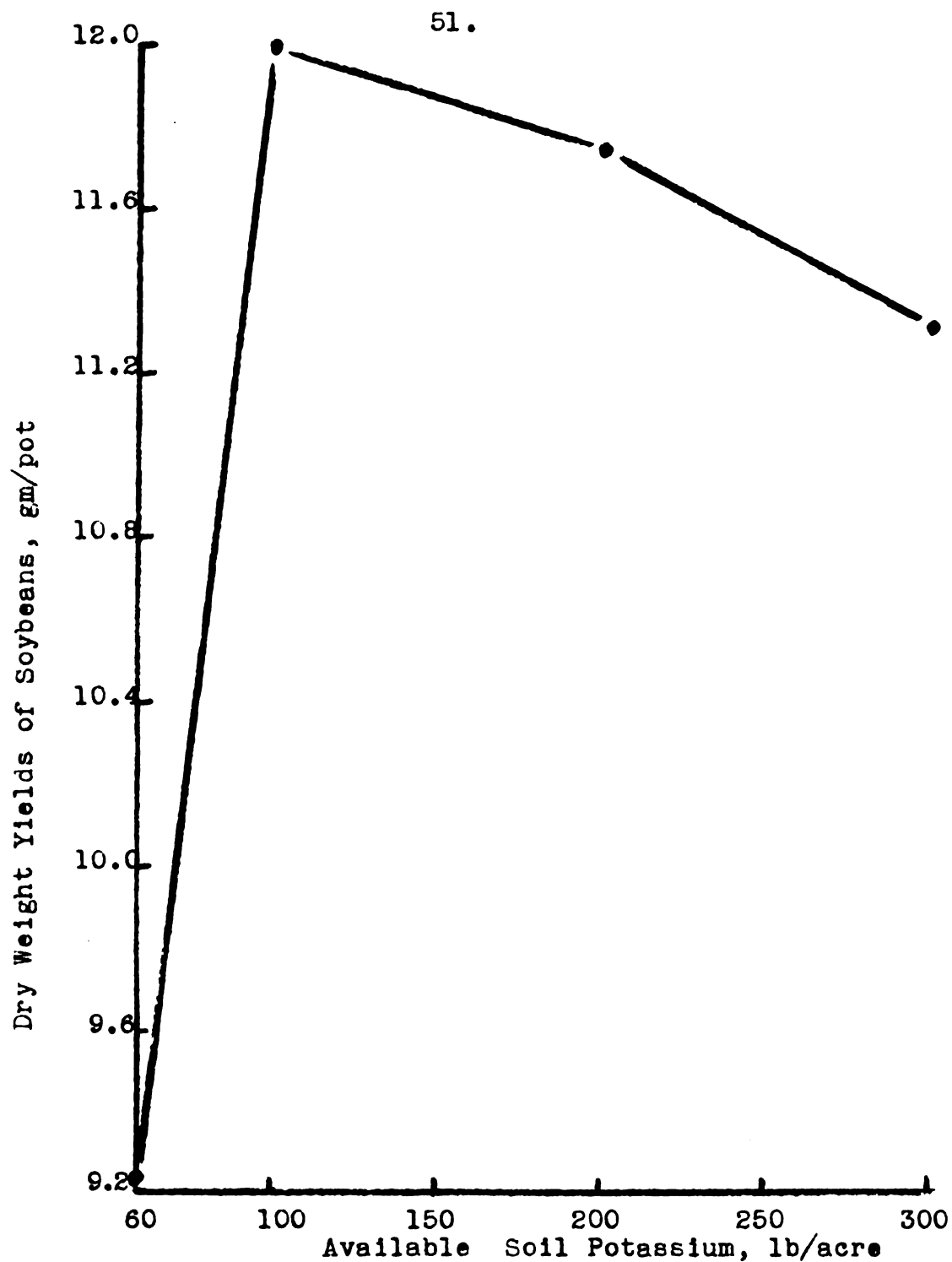


Figure 9. Effect of Available Soil Potassium upon Dry Weight Yields of Soybeans

The application of small amounts of potassium fertilizer to the soil caused great increases in dry weight yields (Figure 9). The 100 pound per acre level of available potassium gave the highest average yields of all potassium treatments. There was a steady yield decrease at the higher rates of potassium. This indicates that the highly significant F value for potassium treatments reported in Table XI was negative. Therefore, it is not surprising that the interaction of two significant factors, type of lime and potassium level, was not significant since one factor caused an increase and the other a decrease in yield.

Oats Crop

No specific deficiency symptoms appeared in the oats plants. Tissue tests indicated that phosphorus and potassium were usually very low in those plants grown at low levels of available phosphorus or potassium, but no definite symptoms became apparent. Visual differences in the size of the plants could be readily detected by the time the plants were heading. Such differences are shown in the photographs in Figure 10. The upper photograph is of plants grown at the four pH levels. A large response to lime application may be noted as the pH of the soil was raised to 5.8. However, above this value, increased growth was less apparent. The lower photograph shows the effects



- a. Effects of soil pH upon growth of oats. From left to right: Treatments I-B2 (pH 4.7), II-B2 (pH 5.8), III-B2 (pH 6.3), and IV-B2 (pH 6.8).



- b. Effects of P and K fertilizers on oats growth. From left to right: Treatments I-0, I-A1, I-B2, and I-C3.

Figure 10. Pictures of oats growth resulting from different soil treatments.

of the four different levels of phosphorus and potassium. Proceeding from the no P-K level ("0" treatment) to high levels of phosphorus and potassium (C3 treatments), there was a steady increase in plant size. The data on dry weight yields support these observations.

After the plants were harvested at the dough stage, they were dried, weighed, and the data analyzed. The results of the analysis of variance are reported in Table VII. There were fewer significant factors affecting the dry weights of the oats than of the soybeans. The growth differences caused by different levels of lime and different types of lime were not significant, but their interaction was highly significant, indicating a difference in yields at a given pH level between the two types of lime. The reason is not apparent. Contrary to the response with soybeans, different phosphorus levels caused highly significant variations in yields. Different potassium levels also caused yield differences significant at the 1% level, as did all triple interactions. The double interaction of type of lime x potassium level was significant at the 1% level, while the PK interaction was significant at only the 5% level. In general, it may be concluded that the growth of oats was influenced more by the levels of available soil phosphorus and potassium than by soil pH (except in highly acid soils) while soybean growth was more sensitive to soil pH.

TABLE VII

Analysis of Variance of Dry Weight Yields of Oats Crop

Source	Degrees of Freedom	F Values
Total	215	--
Replications	3	11.59**
Treatments	53	8.19**
Type of Lime	1	0.13
pH Level	2	0.17
pH Level x Type of Lime	2	12.90**
Phosphorus Level	2	140.13**
Type of Lime x Phosphorus Level	2	1.91
pH Level x Phosphorus Level	4	0.43
Type of Lime x Phosphorus Level x pH level	4	5.24**
Potassium Level	2	8.62**
Type of Lime x Potassium Level	2	69.97**
pH Level x Potassium Level	4	1.55
Type of Lime x pH Level x Potassium	4	10.92**
Phosphorus Level x Potassium Level	4	2.96*
Type of Lime x Phosphorus Level x Potassium Level	4	9.26**
pH Level x Phosphorus Level x Potassium Level	8	20.34**
Error	159	---

* Significant at 5% level

**Significant at 1% level

The effects of liming and fertilizing upon the growth of oats are shown graphically in Figures 11, 12, and 13. In studying the effects of lime, it was found that above pH 5.8, calcium lime caused a steady decrease in yield while the mixed lime caused a steady increase. However, the analysis of variance indicates that these observations were not significant, but the growth differences between the two types of lime at a given pH level was significant. The trend for decreased yields with calcium lime was probably caused by a lack of available soil magnesium. Likewise, phosphorus fertilization caused significant increases in yield, but potassium fertilization increased dry weight production only up to the 200 pound per acre level, then decreased it significantly. The average yields reported for oats were only slightly below those obtained with soybeans, and both crop yields corresponded to an approximate production of 5,000 pounds of forage per acre.

Alfalfa Crop

Since the alfalfa crop was grown in the winter when temperatures varied considerably and a part of the light was artificial, this crop was slower in becoming established than were the other two crops. Also, since only one harvest of alfalfa was taken and since alfalfa tends to establish a good root system in its initial growth at the expense of its top growth, the yields of alfalfa dry matter

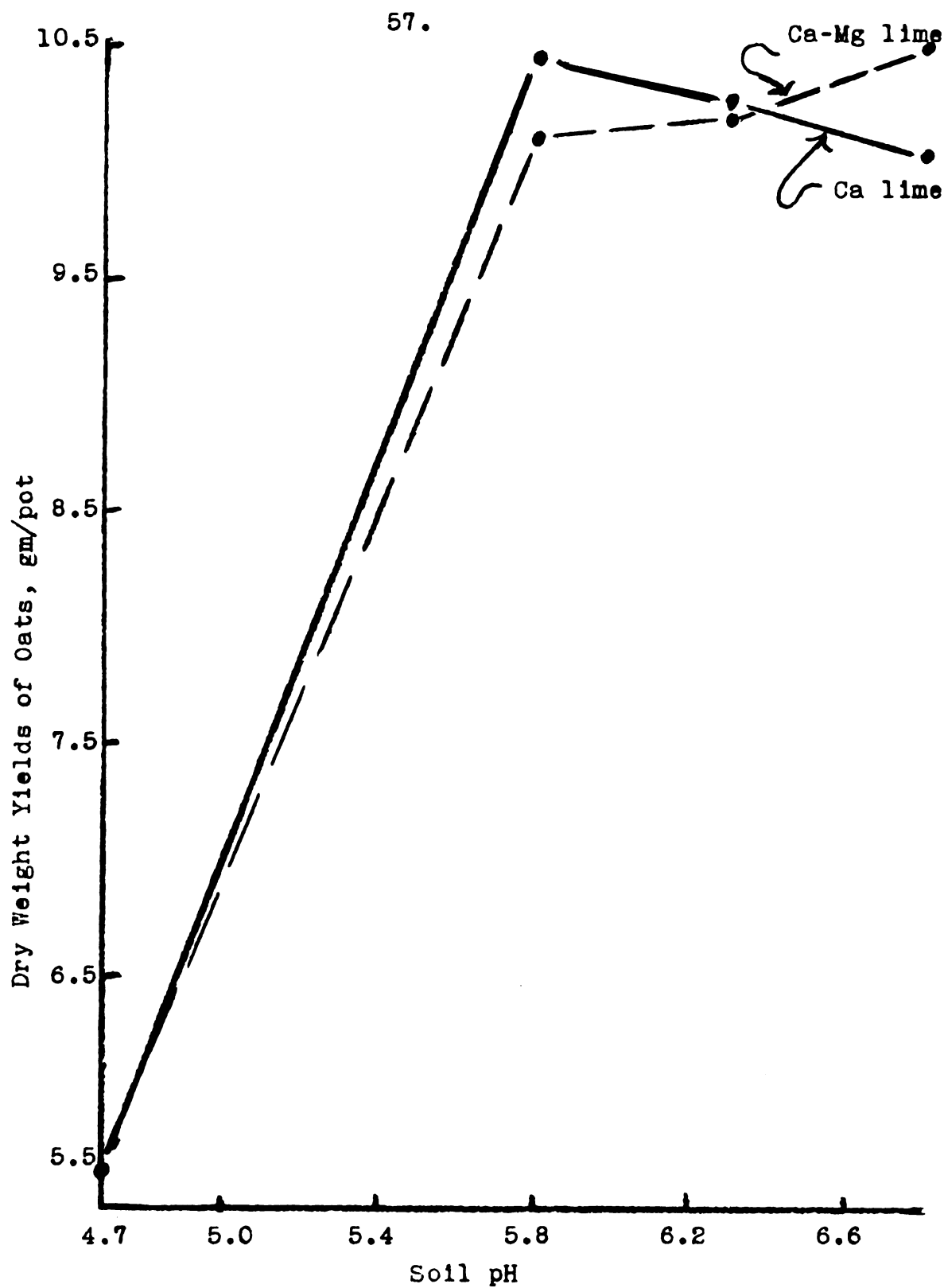


Figure 11. Effect of Soil pH upon Dry Weight Yields of Oats.

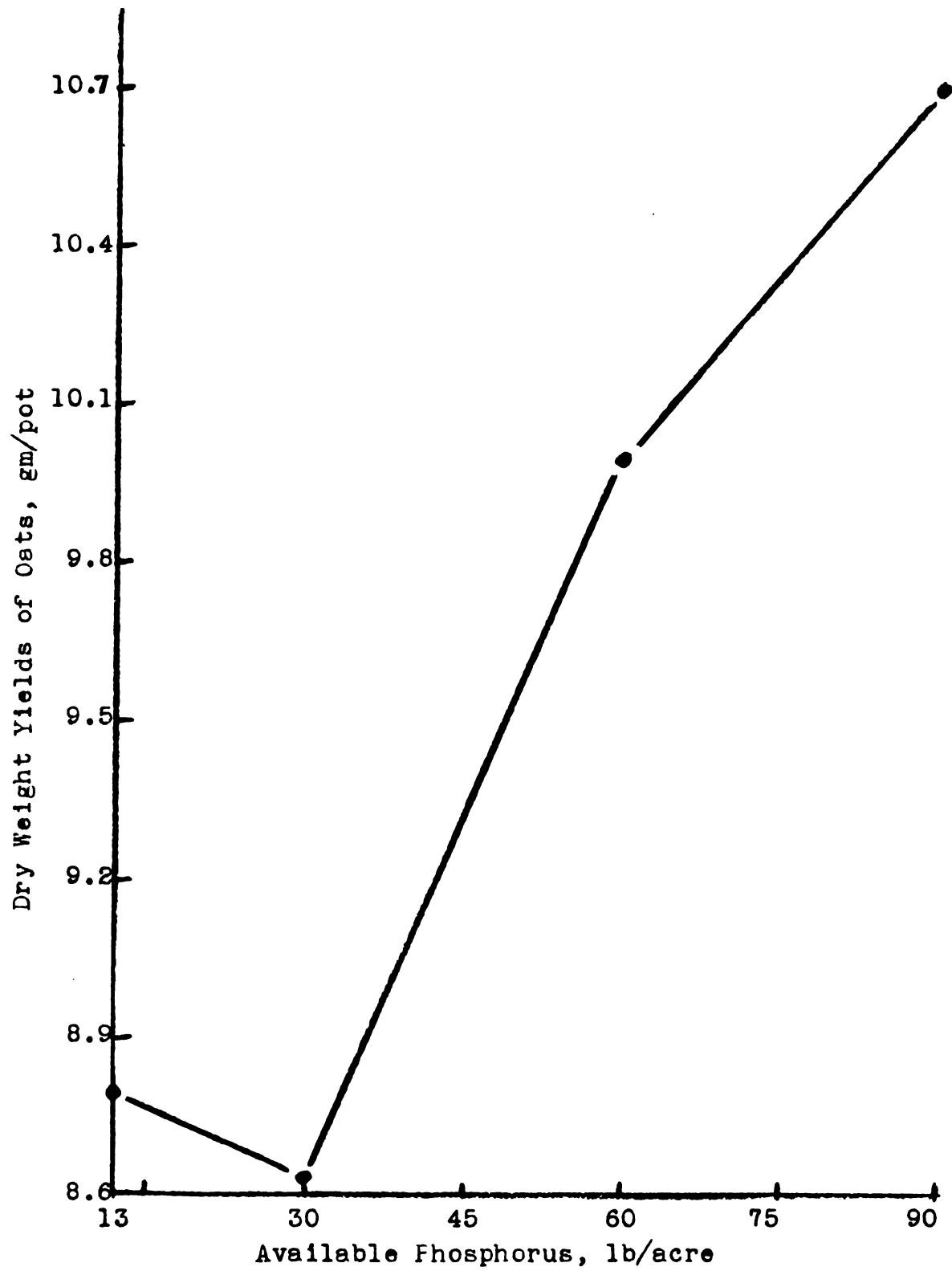


Figure 12. Effect of Available Soil Phosphorus upon Dry Weight Yields of Oats.

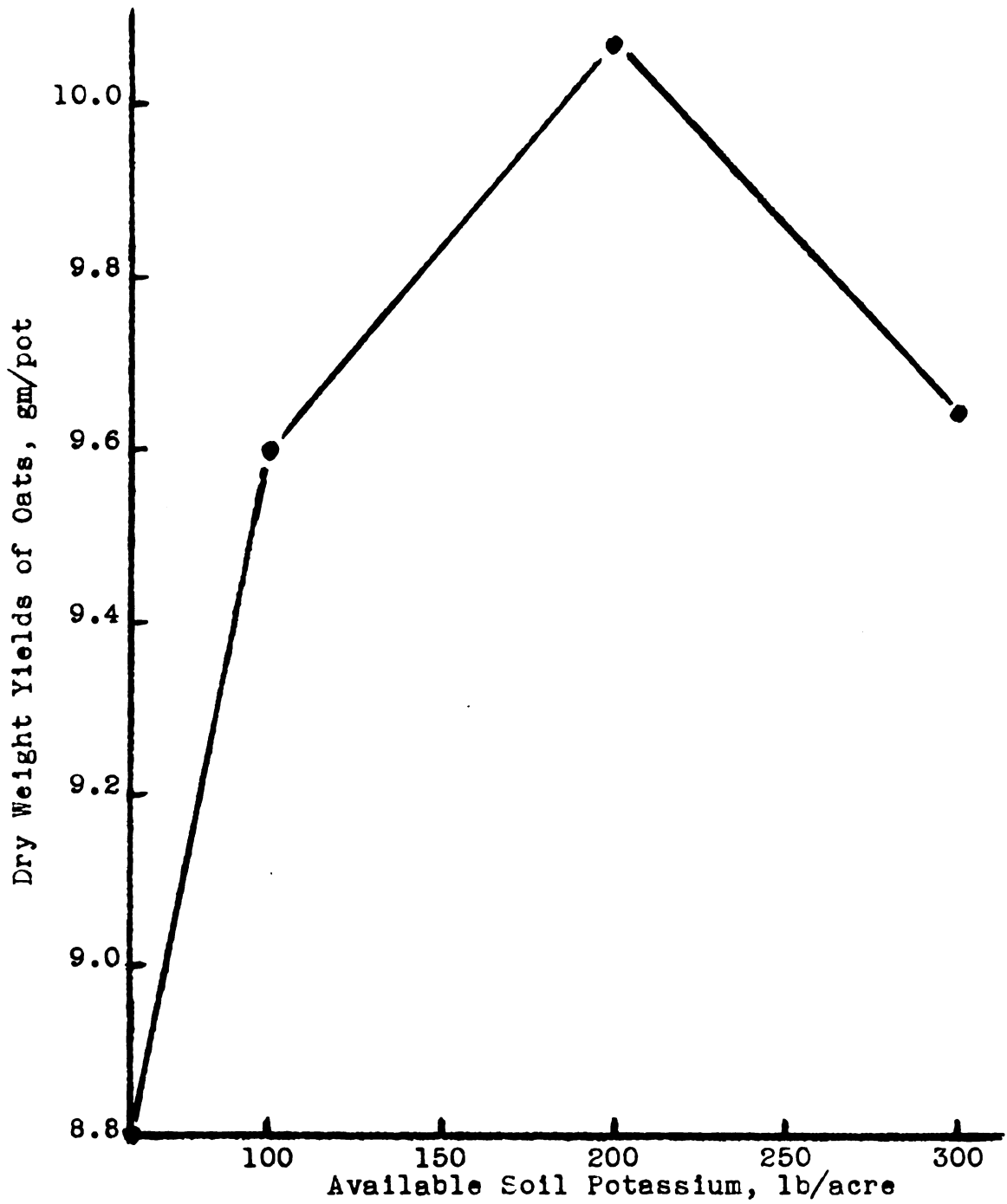


Figure 13. Effect of Available Soil Potassium upon Dry Weight Yields of Oats.

were relatively low.

Although no specific deficiency symptoms were recognized on any of the plants, all plants grown at a soil pH of 4.7 were severely stunted in growth and were definitely chlorotic. These plants were very slow in becoming established and made very little growth. No difference was detected between the growth of the plants at the higher pH levels (Figure 14). The phosphorus and potassium treatments appeared to have no appreciable effect upon the size of the plants during their period of growth.

These conclusions were supported by the analysis of variance of the dry weight yields of the alfalfa as it is reported in Table VIII. It should be recalled that the "no treatments" (treatments I and O) were omitted from the analysis of variance, so the effects of increasing soil pH from 4.7 to 5.8 are not shown. The fourth order interaction was the only highly significant factor, and no single treatment of itself was significant. The interaction of type of lime x level of phosphorus seemed to have some significance, since in every place that these two factors occurred together, they gave a yield response that was significant at the 5% level. This is interpreted to mean that magnesium may be necessary in the phosphorus metabolism of the plant. Work by Truog (94) led him to the conclusion that the frequent failure of obtaining a response to phosphate fertilization by alfalfa may be due to



- a. Effects of lime and fertilizers on alfalfa growth. From left to right: Treatments I-0, I-B3, and II-B3.



- b. Effect of soil pH on alfalfa growth. From left to right: Treatments I-0, II-0, III-0, and IV-0.

Figure 14. Pictures of alfalfa growth resulting from different soil treatments.

TABLE VIII

Analysis of Variance of Dry Weight Yields of Alfalfa Crop

Source	Degrees of Freedom	F Values
Total	215	---
Replications	3	6.29**
Treatments	53	0.75
Type of Lime	1	0.18
pH Level	2	2.51
Type of Lime x pH Level	2	0.18
Phosphorus Level	2	0.27
Type of Lime x Phosphorus Level	2	3.39*
pH Level x Phosphorus Level	4	1.21
Type of Lime x pH Level x Phosphorus	4	2.47*
Potassium Level	2	0.63
Type of Lime x Potassium Level	2	0.45
pH Level x Potassium Level	4	0.54
Type of Lime x pH Level x Potassium	4	2.41
Phosphorus Level x Potassium Level	4	0.63
Type of Lime x Phosphorus Level x Potassium Level	4	3.13*
pH Level x Phosphorus Level x Potassium Level	8	1.70
Type of Lime x Phosphorus Level x Potassium Level x pH Level	8	4.11*
Error	159	--

* Significant at 5% level

**Significant at 1% level

a low supply of available soil magnesium. These results support that theory.

The effects of soil pH upon the average dry weight yield of alfalfa are shown in Figure 15. The first application of lime caused a large increase in dry matter production, but further applications resulted only in minor increases. There was no appreciable difference between types of lime. Graphs of the effects of phosphorus and potassium fertilization were not included because they showed no significant increases. The "0" treatment average was only slightly below that of the other treatments (3.64 grams/pot as compared to 3.74 for the 90 lb/acre phosphorus level or 3.68 for the 300 lb/acre potassium level).

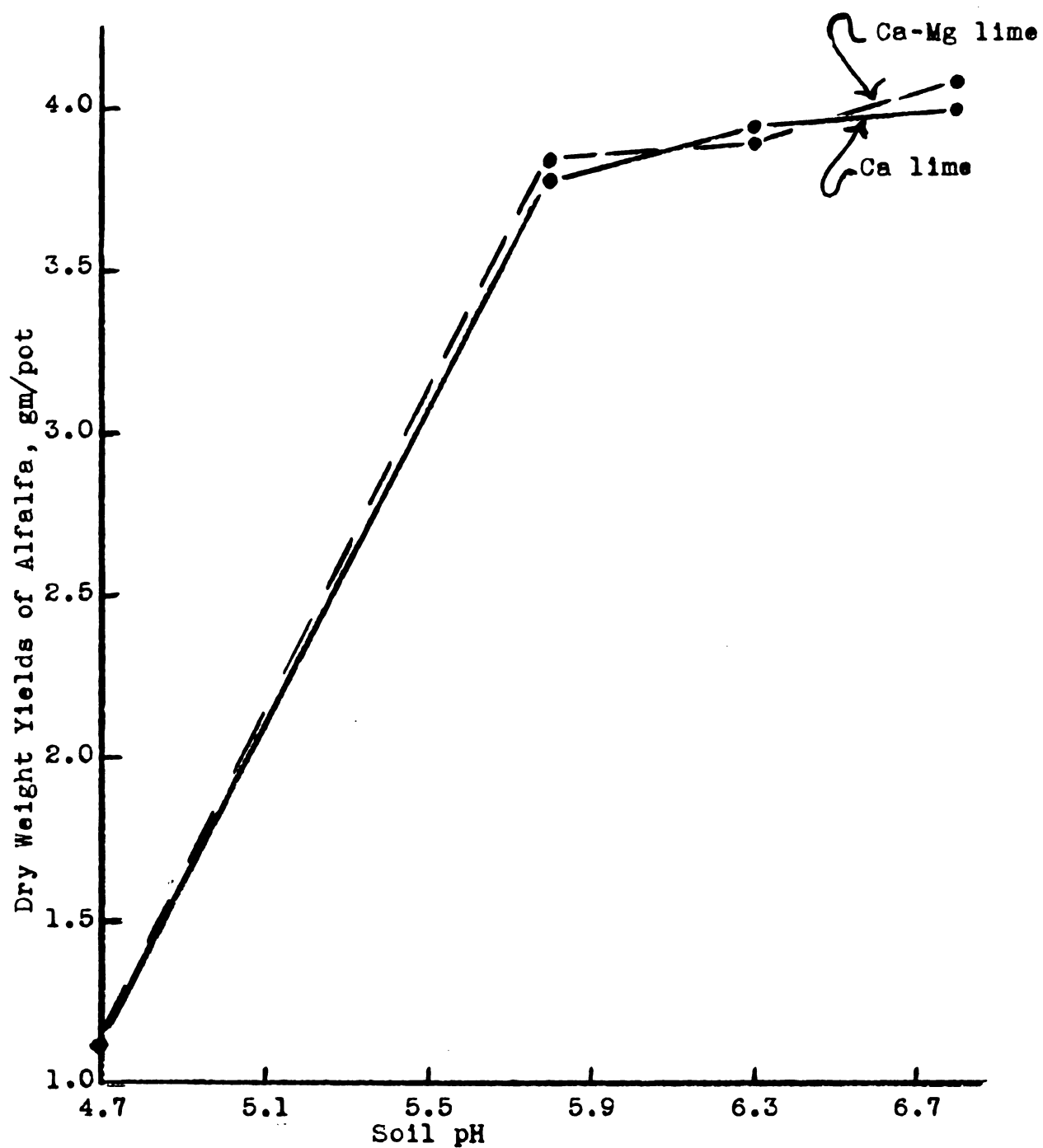


Figure 15. Effect of Soil pH upon Dry Weight Yields of Alfalfa.

Effect of Soil Nutrients on Plant Composition

The results of the chemical analyses of the soybean, oats, and alfalfa crops are presented in Tables XXI, XXII, and XXIII respectively in the appendix.

Effects of Calcium on Plant Composition

Lime, in the form of calcium carbonate, was added to the soil to raise the soil pH from 4.7 to a maximum of 6.8. In doing this, the availability of many of the soil nutrients was altered, some to a considerable extent. This change in availability was usually reflected to some degree in the chemical composition of the crop. The degree to which this was true varied greatly for the different nutrients, as well as with the different crops.

The effects of calcium carbonate at the four pH levels upon the percent composition of the soybeans are presented graphically in Figure 16. The percentage composition values graphed in this figure were the averages from all plants receiving the same lime treatment, making a total of ten plant samples for each value reported. These figures express only the effects of liming, since all levels of phosphorus and potassium were included in the average.

Since it has been shown earlier that the degree of base saturation was almost a linear function of the soil pH under the conditions of this experiment, the effects of the calcium lime on plant composition will be discussed using



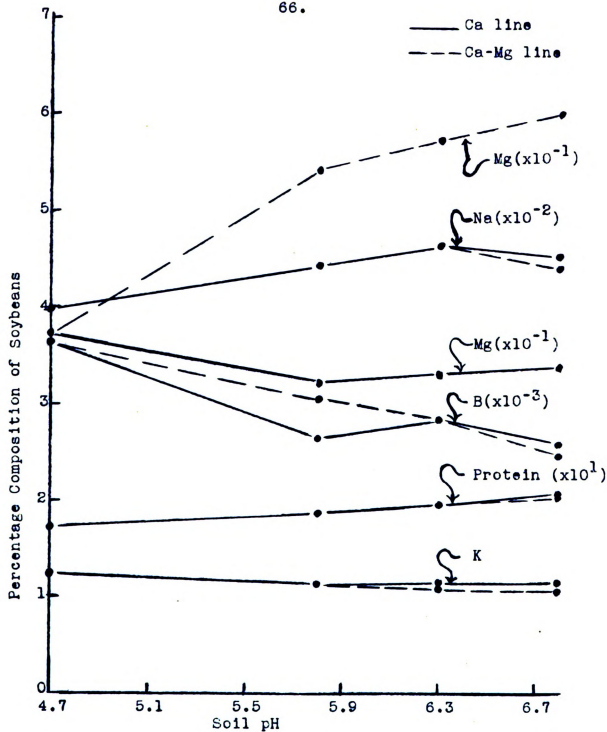


Figure 16. Effect of Soil pH upon Percentage Composition of Soybeans.

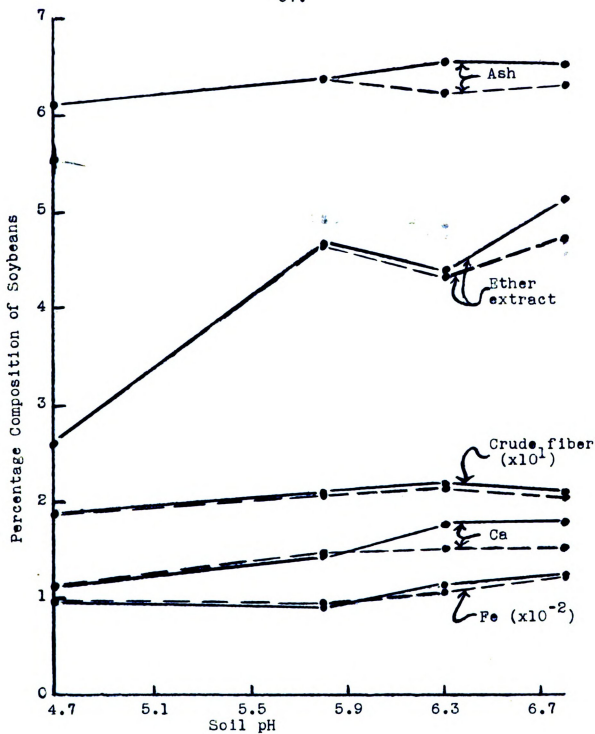


Figure 16. (continued)

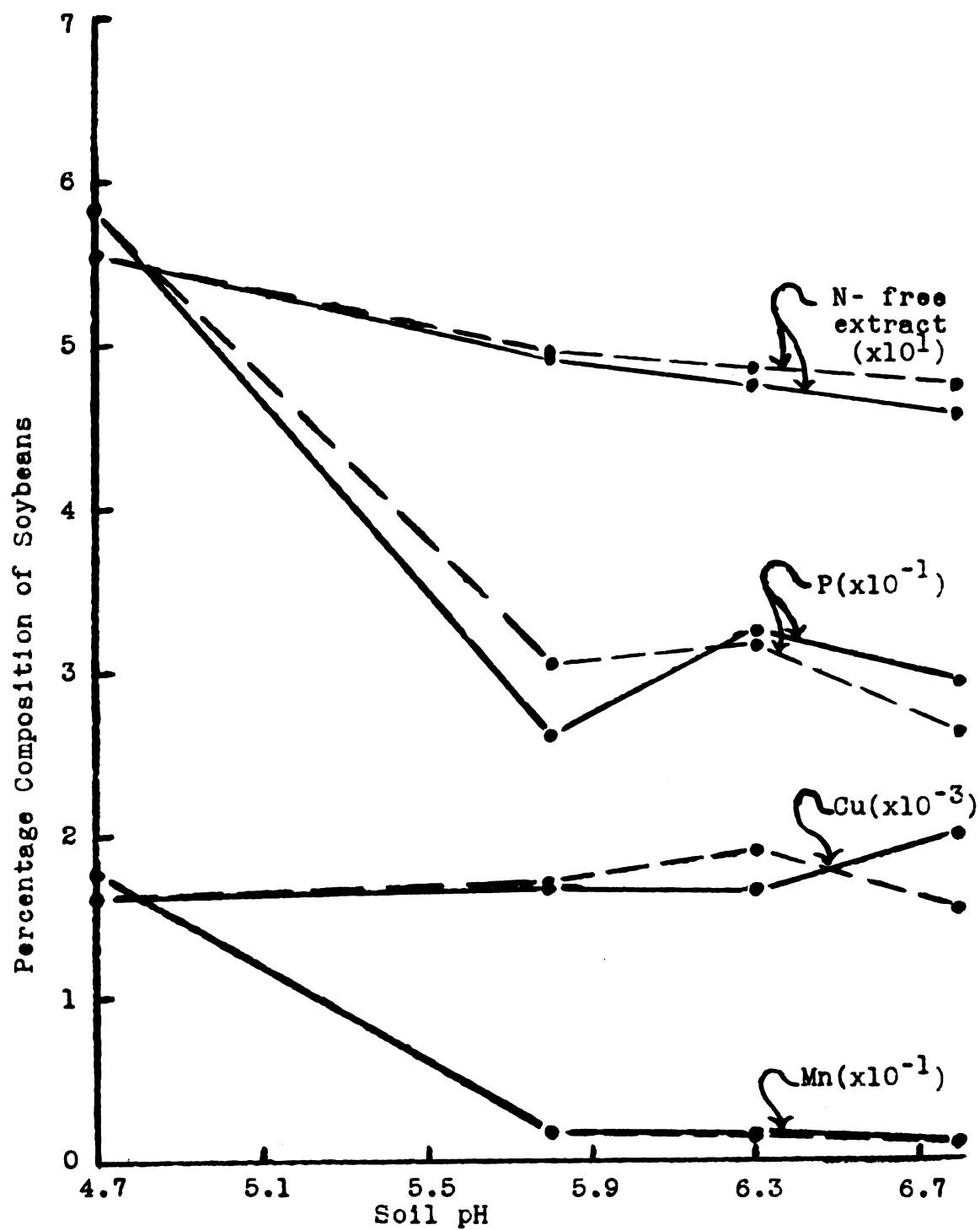


Figure 16. (continued)

either soil pH or percent saturation as measures of the calcium status of the soils receiving calcium carbonate.

From Figure 16 it may be seen that additions of calcium carbonate to the soil caused a large increase in the percentages of ether extract, and somewhat smaller increases in the content of ash, crude fiber, protein, sodium, calcium, and iron. Decreases occurred in the percentages of N-free extract, boron, magnesium, phosphorus, and manganese. The concentrations of potassium and copper in the soybeans were essentially unaltered by liming.

One of the most outstanding changes in the chemical composition of the soybeans as a result of liming was the large decrease in the phosphorus content of the plant. This decrease occurred with the addition of the first increment of lime. The changes in the average percent phosphorus in the plants were probably not significant at soil pH values of 5.8 or above. The decrease in phosphorus content cannot be explained as being the result of reduced availability since the availability of soil phosphorus should have been at its maximum at these pH levels. Therefore, it must be concluded that the decrease was the result of some physiological phenomenon within the plant. The cause of this phenomenon, however, cannot at this time be explained.

The almost linear decrease of the percent boron in the plant tissue with added increments of lime is also of interest. Much of this decrease was probably due to the reduced availability of boron at higher pH levels. According to the data compiled from the literature by Goodall and Gregory (38), soybean plants should contain at least 30 parts per million boron for maximum yield. The data reported in this thesis suggest that this limit is too high, since maximum soybean yields were obtained at a soil pH of 6.8, at which point the average boron concentration in the soybeans was about 25 parts per million.

The rapid rise in the ether extract content of the plant with increased soil pH indicates that higher pH values favored fat and lipid production. In animal studies it is accepted as a general rule that fat accumulation results only when the animal receives food in excess of its maintenance requirements. If such a concept were applicable to plant growth, the results obtained (Figure 16) indicate that decreasing the soil acidity allowed the soybean plant to accumulate energy in the form of fats and lipoids in excess of its growth requirements.

Although the increase in percent protein with increasing soil pH was uniform and linear, the total increase was small and may not have been significant. Also, it is of interest to note that raising the soil pH to 5.8 caused a ten-fold decrease in manganese content. Likewise, it may

be observed (Figure 16) that, while the calcium content of the soybeans increased slightly with increased pH, the potassium content was unaltered, and the magnesium content was slightly decreased.

The effects of the addition of calcium to the soil upon the percent composition of oats are shown in Figure 17. Small decreases occurred in the percent ash, boron, and copper, while larger decreases occurred in phosphorus, iron, and manganese. The percent sodium, ether extract, and calcium showed noticeable increases, while the contents of magnesium, N-free extract, crude fiber, potassium, and protein exhibited only minor changes.

According to the data compiled by Goodall and Gregory (38), no liming treatment reduced the average concentration of any mineral element in the oats plants to such an extent that it was deficient (below the "critical levels"). Even though liming caused large decreases in the iron, phosphorus, and manganese content of the oats, the concentration of these elements did not approach the limiting values quoted by these authors. Although this reference cited no upper values at which iron and manganese may become toxic to plant growth, the poor growth and high concentration of these two elements in the plant tissue suggests that they were approaching such a limit in those oats plants grown at a soil pH of 4.7.

Liming reduced the uptake of manganese in both the

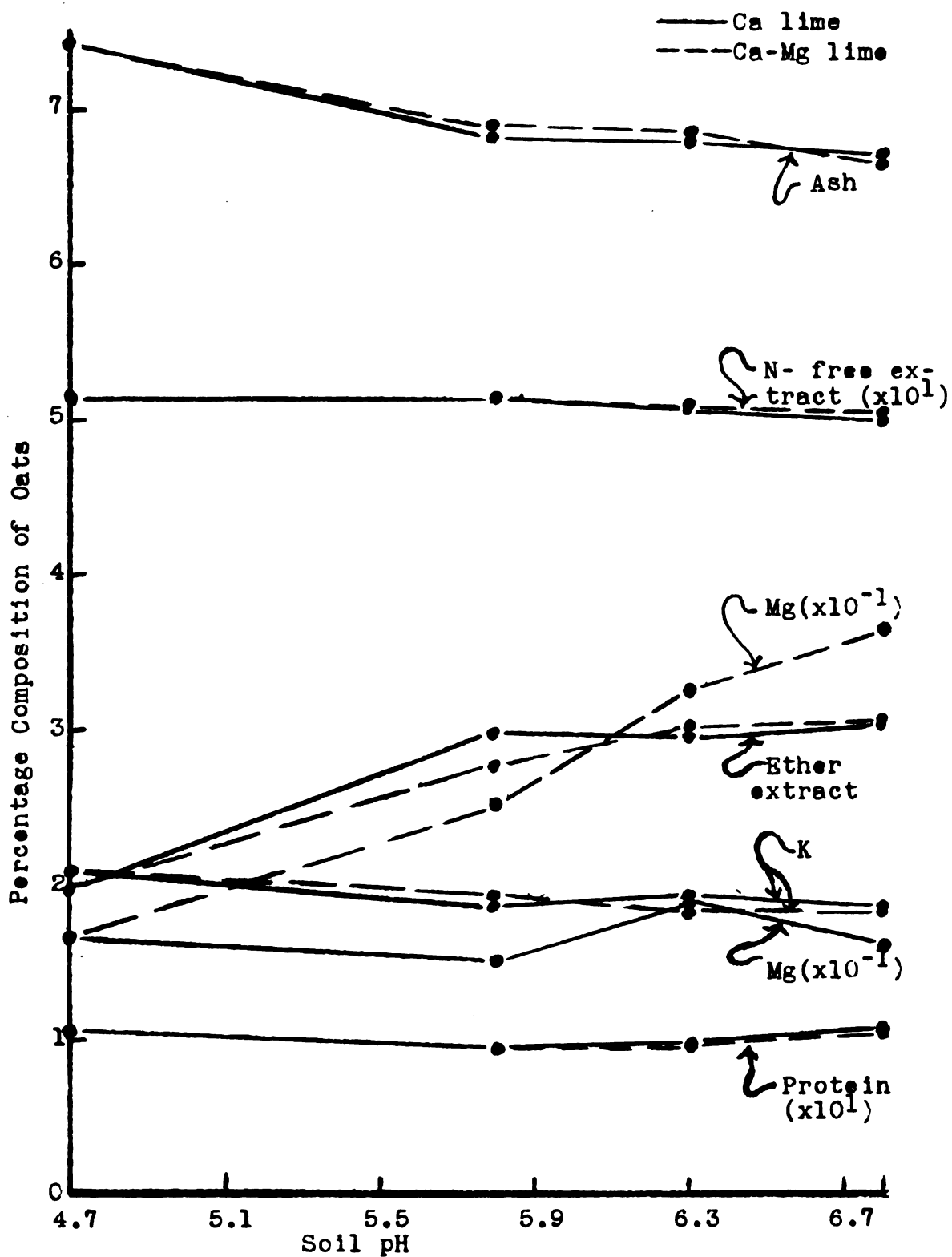


Figure 17. Effect of Soil pH upon Percentage Composition of Oats.

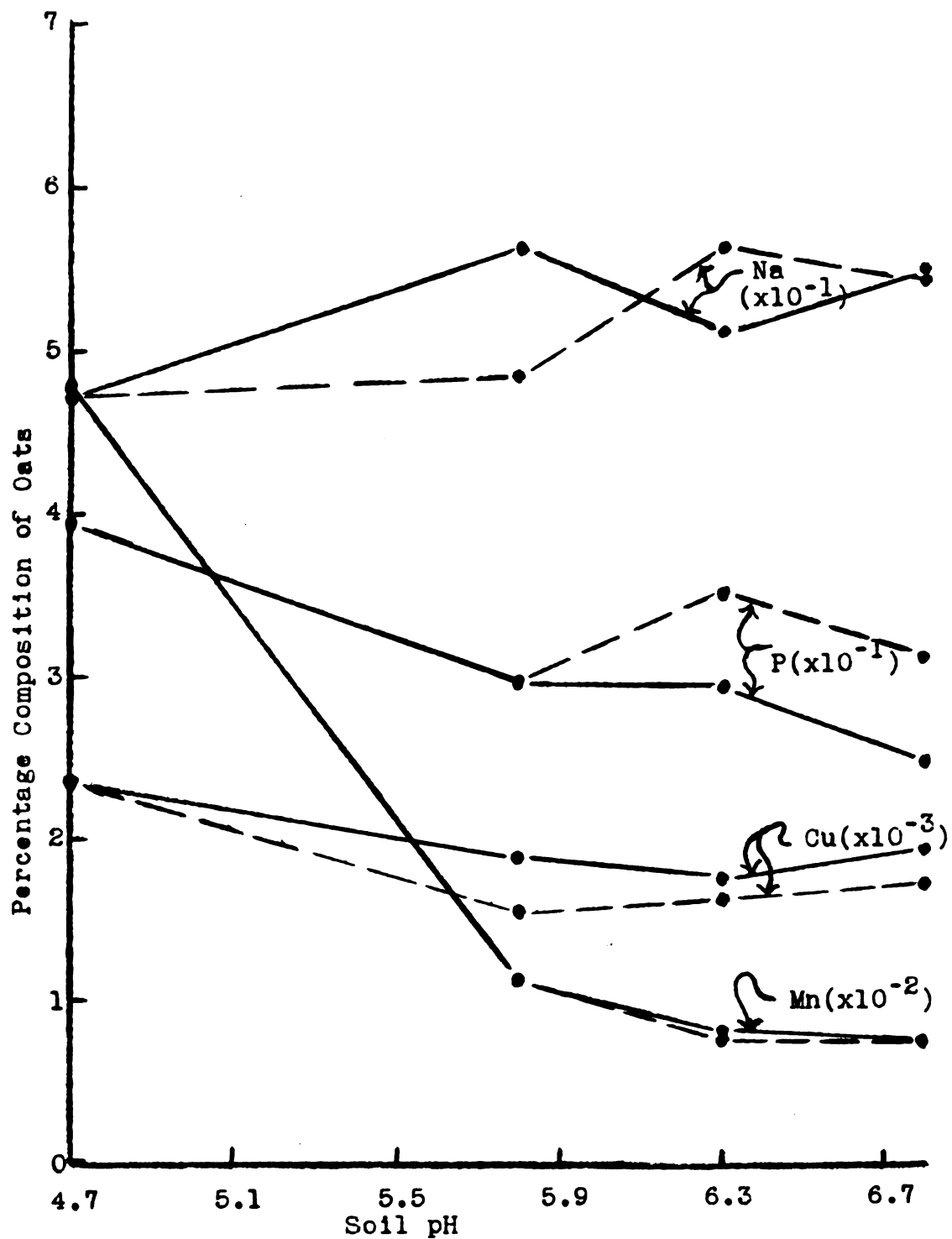


Figure 17. (continued)

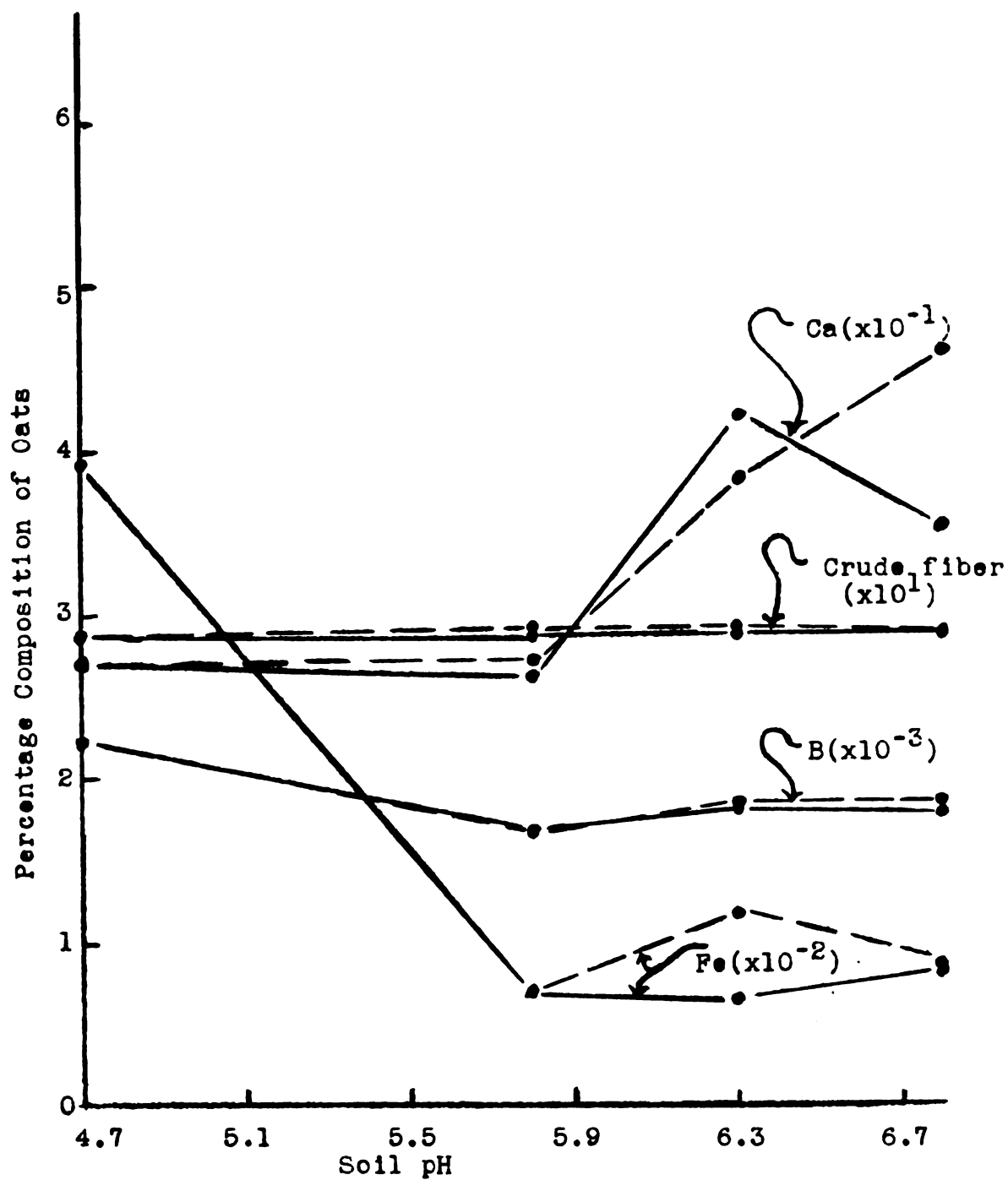


Figure 17. (continued)

soybeans and oats. However, this soil treatment resulted in decreased iron uptake by the oats, but increased iron uptake by the soybeans. Therefore, the soybean analyses support the proposal of Somers and Shive (89) and others (16, 46) that iron and manganese are antagonistic; that is, factors causing an increase in the concentration of one caused a decrease in the other. On the other hand, the results of the oats analyses definitely contradicted this idea, so the relationship is questionable.

The effects of increasing the percent calcium saturation of the soil upon alfalfa composition are expressed graphically in Figure 18. This practice tended to cause a slight decrease in the percentages of ether extract, potassium, boron, phosphorus, and iron. The manganese content was decreased well over ten-fold by adding calcium carbonate to increase the soil pH from 4.7 to 5.8. On the other hand, this amendment appeared to have caused a slight increase in the protein content and a larger increase in the percentage of calcium in the alfalfa.

Goodall and Gregory (38) found that alfalfa plants containing less than 12 parts per million boron showed deficiency symptoms, and that maximum yield was not obtained unless the concentration of boron was at least 20 parts per million. Almost all plants in this experiment, except some of those grown at a soil pH of 6.8, contained at least 20

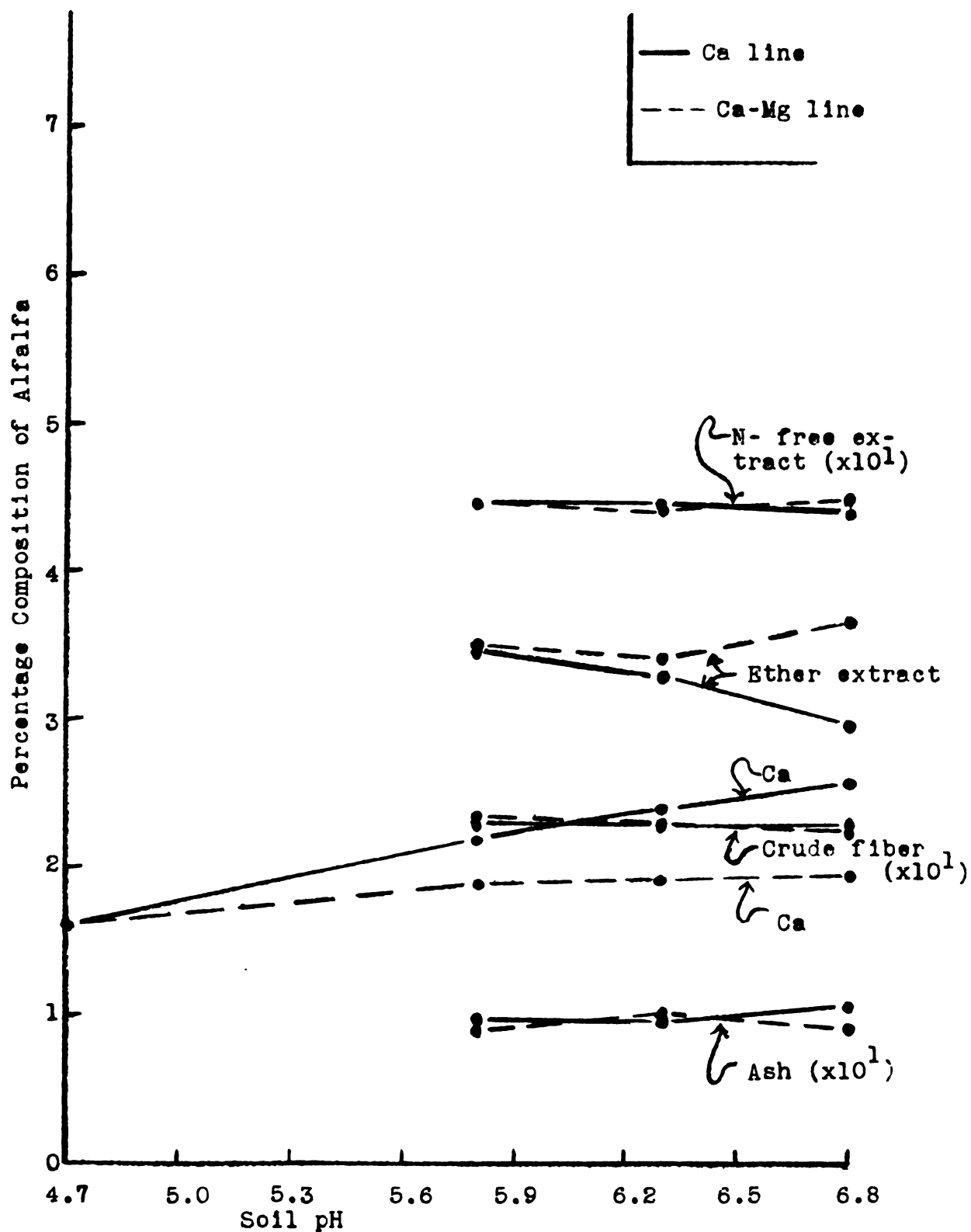


Figure 18. Effect of Soil pH upon Percentage Composition of Alfalfa.

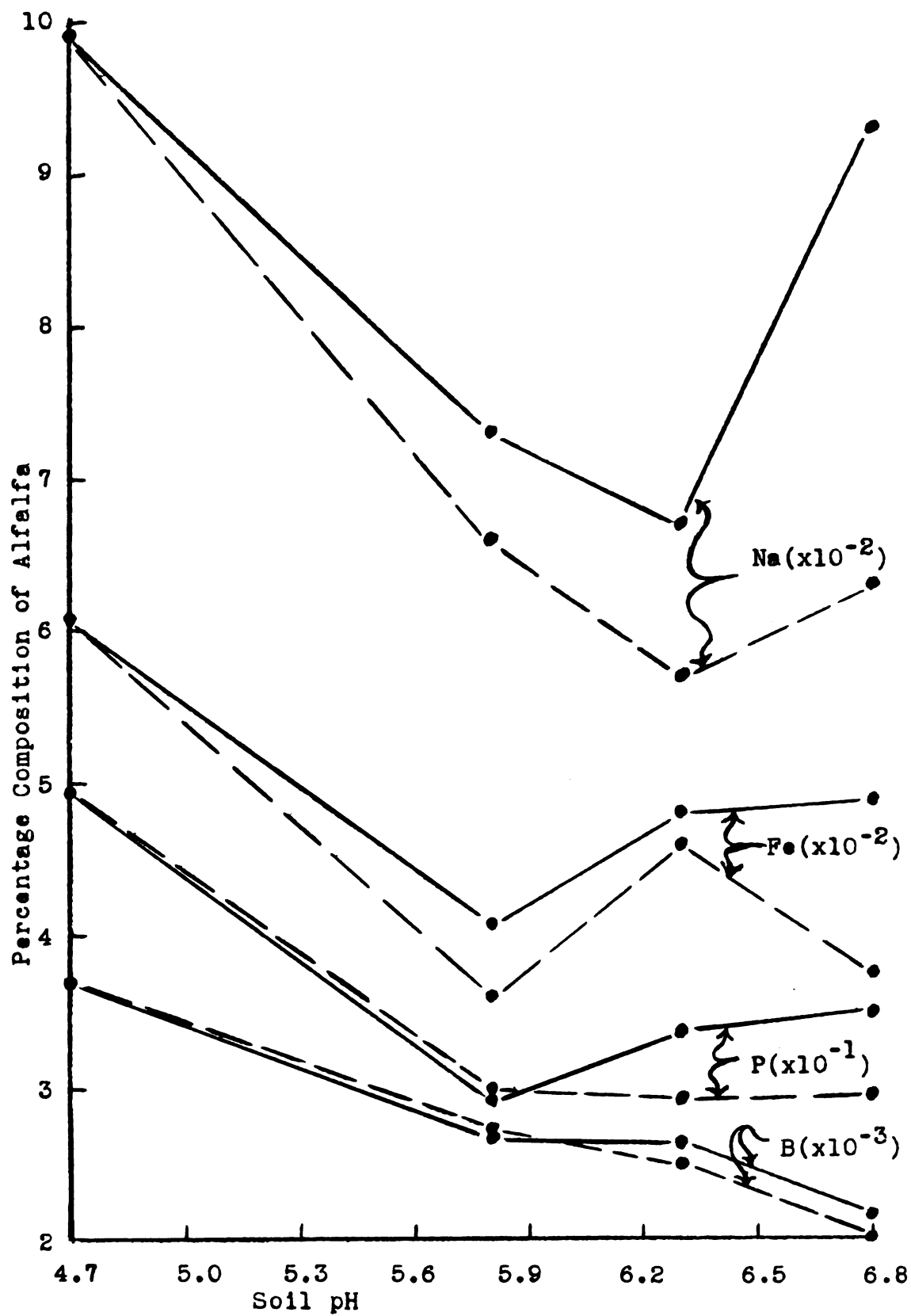


Figure 18. (continued)

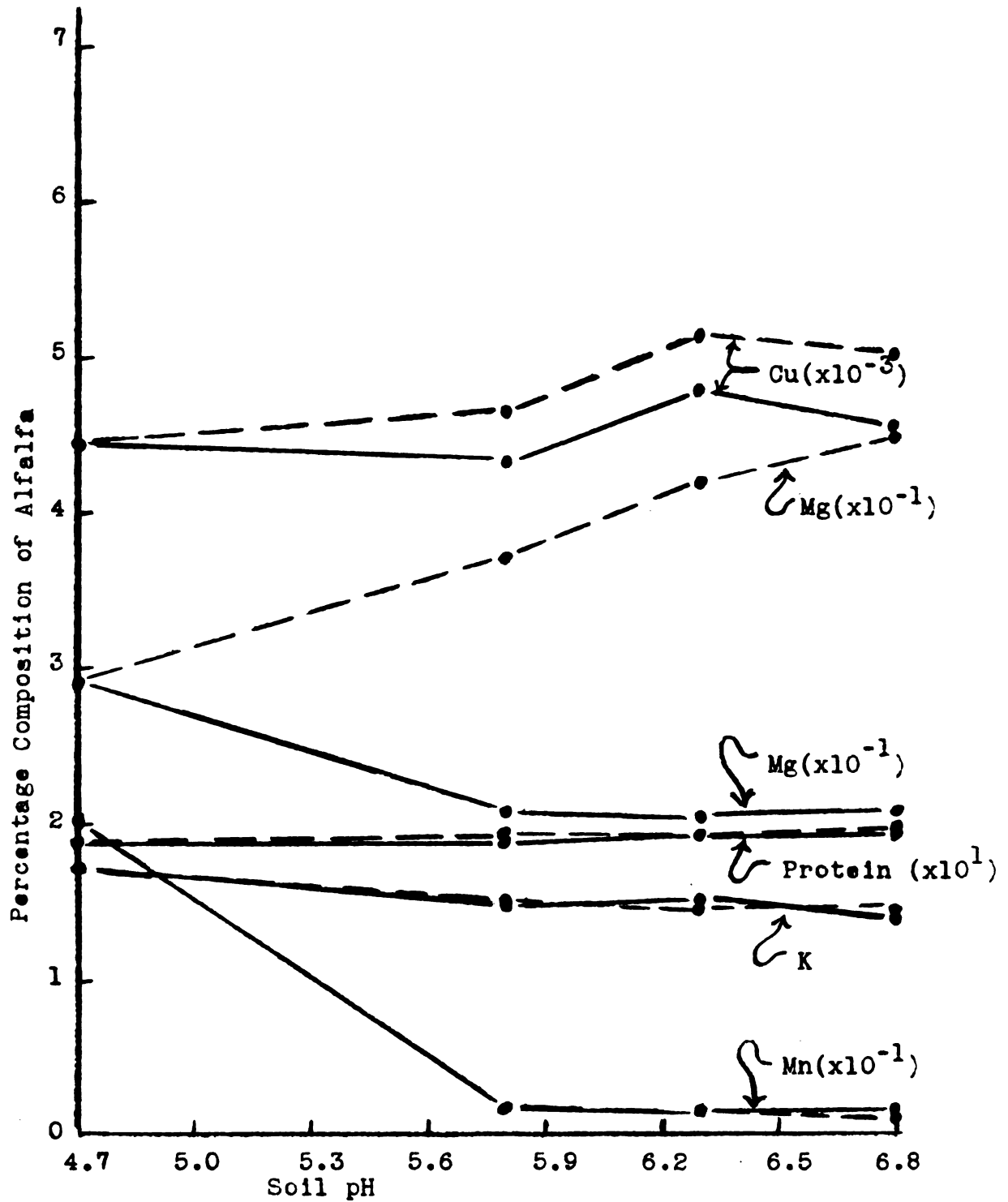


Figure 18. (continued)

parts per million boron. However, in this experiment, those plants containing about 20 parts per million boron made the greatest growth.

The response of the alfalfa to an increase in the percent calcium saturation of the soil was very similar to that observed for the soybean crop (Figure 16) except that in the alfalfa, the decrease in the percent of plant phosphorus was much smaller. Also the N-free extract content of the alfalfa was not decreased and the iron content was not increased by additions of calcium carbonate. However, in general, the responses of soybeans and alfalfa to calcium carbonate appeared to be quite similar. Likewise, alfalfa responded to liming in a manner similar to the oats plants except that neither a definite decrease in percent ash nor increase in crude fiber was observed. Also, the decrease in the percent iron was much smaller than in the oats. In agreement with the work of Collander (24), the concentration of the divalent cations, calcium and magnesium, was considerably greater in the alfalfa than in the oats, but the opposite trend was observed in regard to the concentration of the monovalent cations, potassium and sodium.

The data concerning the effects of soil treatment upon plant composition were analyzed statistically by two methods. Since it was necessary to composite the replicates for the chemical analyses, it was not possible to make an analysis

of variance upon the resulting data. Therefore, correlation coefficients were calculated to measure the effects of the intensity of supply of the various nutrients upon plant composition. The coefficient of likelihood was also calculated for the variations in plant composition resulting from soil treatment.

In Table IX are listed the various correlation coefficients between the percent calcium saturation of the soil and the percentage of each chemical constituent in the three species of plants. A correlation coefficient of 0.232 was required for significance at the 5% level, and 0.302 at the 1% level according to Snedecor (88).

The results obtained (Table IX) show that the percent ether extract, crude fiber, protein, iron, and calcium in the soybeans gave highly significant positive correlations with the percent calcium saturation of the soil, while the N-free extract, boron, phosphorus, and manganese contents gave negative "r" values significant at the 1% level. Total bases per 100 grams of soybean dry material were positively correlated at the 5% level with the percent calcium saturation of the soil.

In regard to the nutritive value of the soybean plants, these results indicate that liming had a favorable effect in that it increased ether extract, protein, iron, and calcium, but that it had an unfavorable effect in that

TABLE IX

Correlation Coefficients Between Percent Calcium
Saturation of the Soil and Plant Composition

Chemical Constituent	"r" Values for:		
	Soybeans	Oats	Alfalfa
Ash	0.2299	-0.1021	0.2919*
Crude Fiber	0.6886**	-0.0811	0.1621
Ether Extract	0.5226**	0.1710	0.0184
Protein	0.4625**	0.1257	0.0816
N-free Extract	-0.6464**	-0.1737	0.1296
Potassium	-0.1437	-0.1072	0.3417**
Sodium	0.1919	0.0707	0.0941
Boron	-0.4100**	-0.3449**	-0.4148**
Phosphorus	-0.3723**	-0.0253	-0.1140
Iron	0.3045**	-0.3128**	-0.0156
Magnesium	-0.1250	-0.0473	-0.1497
Manganese	-0.6400**	-0.2140	-0.5140**
Calcium	0.3728**	0.3913**	0.5292**
Copper	0.0752	-0.0924	-0.0671
M.e. bases/100 gms.	0.2729*	0.1950	0.5542**

* Significant at the 5% level

**Significant at the 1% level

it decreased the percent N-free extract and phosphorus while increasing the crude fiber content.

The "r" values listed in Table IX for the oats crop indicate that increasing the percent calcium saturation of the soil increased the calcium content of the plant significantly, but that it also caused significant decreases in the percent boron and iron in the oats. From these results, it appears that liming increased the nutritive value of the oats very little.

In the alfalfa crop, the percent calcium saturation of the soil showed highly significant positive correlations with only the percent calcium and total bases per 100 grams of plant material. Negative correlation coefficients were obtained in regard to the potassium, boron, and manganese contents.

The coefficients of likelihood, given in Table X for the variations in plant composition caused by liming, were calculated by the formula (26):

$$L = \frac{\sum (x_i - \bar{x})^2}{n-1}$$

where σ is the standard deviation, and k is the number of standard deviations (or treatments) being compared. The significance of these L values was determined from the table given by Croxton and Cowden (26). A value less than 0.757 was required for significance at the 1% level and less than



TABLE X

Coefficients of Likelihood for the Variations in
Plant Composition Resulting from Changing the Soil pH

Chemical constituent	L values for:		
	Soybeans	Oats	Alfalfa
Ash	0.9999	0.7775*	0.5647**
Crude Fiber	0.9137	0.8562	0.9802
Ether Extract	0.6188**	0.8901	0.9063
Protein	0.7336**	0.8487	0.3294**
N-free Extract	0.7299**	0.8818	0.8718
Potassium	0.7487**	0.9932	0.9886
Sodium	0.7190**	0.9889	0.9615
Boron	0.5496**	0.6230**	0.9163
Phosphorus	0.4886**	0.8317	0.8000*
Iron	0.7262**	0.3335**	0.7959*
Magnesium	0.8957	0.5994**	0.8015*
Manganese	0.3440**	0.4155**	0.2439**
Calcium	0.7238**	0.8528	0.8188
Copper	0.7770**	0.4878**	0.9205
M.e. bases/100 gms	0.7543**	0.9046	0.9122

* Significant at 5% level

** Significant at 1% level

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0.812 at the 5% level. Since the L value is only a measure of variation derived from the standard deviation of a series of treatments (seven liming treatments in this case), its value is subject to the same factors that determine the value of the standard deviations. Thus if the variations in the percent of a particular constituent in the plant resulting from one series of treatments were large, there would be considerable variation among the standard deviations for those treatments, so the possibility of the L value being significant would be increased. On the other hand, if the standard deviations within a given type of treatment tended to be uniform, indicating that the soil treatment had little effect upon the percent of this constituent in the plant, the L value would have less significance. Thus, a significant coefficient of likelihood for a given chemical constituent indicates that the variations in that constituent caused by different levels of a given kind of soil treatment were not due to chance; that is, it may be concluded that real differences exist between the composition of the samples, or that the samples are not all from the same population.

From Table X it may be seen that highly significant variations were obtained between the different lime treatments for the percentages of ether extract, protein, N-free extract, potassium, sodium, boron, phosphorus, iron, manganese, calcium, and copper in the soybeans. However, it must

be realized that these coefficients of likelihood measured only the magnitude of the variations in plant composition, but not the direction. This must be ascertained from other sources, such as the graphs or the correlation coefficients of plant composition.

In the oats plants, the variations in the ash, boron, iron, magnesium, manganese, and copper contents showed some significance between the different lime treatments. It may be observed that the percentages of all these constituents except ash and magnesium also varied significantly in the soybeans. Likewise, in the oats, all the minor elements determined gave significant variations by this method of analysis.

The data in Table X indicate that the variations in the percent ash, protein, and manganese in the alfalfa were significant at the 1% level and that phosphorus, iron, and magnesium percentages differed significantly at the 5% level. Thus, significant variations resulting from raising the soil pH with lime were observed only in the iron and manganese contents of all three crops.

The results of these three methods of analysis of the data on the effects of liming upon plant growth and composition are summarized in Table XI. These conclusions are based upon the trends indicated in the data and graphs in Figure 16, Table IX, and Table X, taking into consideration the limitations inherent in each of these three methods of

TABLE XI

Summary of the Effects of Lime Applications to the Soil upon Plant Growth and Composition

Increase			Decrease			No effect ¹		
Soybeans	Oats	Alfalfa	Soybeans	Oats	Alfalfa	Soybeans	Oats	Alfalfa
Dry weight***	Dry weight* weight**	Dry weight**	N-free ex- tract***	Ash**	Potas- sium*	Copper	Crude fiber	Crude fiber
Ash*	Ether extract*	Ash**	Potas- sium*	N-free extract*	Boron**	Magnes- ium ²	Pro- tein	Ether extract
Crude fiber**	Cal- cium***	Protein **	Boron***	Potas- sium*	Phospho- rus*		Sodium	N-free extract
Ether ex- tract***		Calcium **	Phospho- rus**	Boron**	Iron**		Magnesium ²	Sodium
Protein**			Mangan- ese***	Phos- phorus*	Mangan- ese***			Magnesium ²
Sodium**				Iron***				Copper
Iron**								
Calcium**								

¹Variations were of no significance

²Increased considerably with Ca-Mg lime, but not with Ca lime.

* Variations were of questionable significance.

** Variations were moderately significant.

***Variations were definitely significant.

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presenting data. It may be observed, however, that, in general, these three sources suggested similar tendencies.

The data in Table XI show that liming caused definite increases in dry weight and percent crude fiber, ether extract, protein, sodium, iron, and calcium in the soybeans. Meanwhile, the percent N-free extract, boron, phosphorus, and manganese decreased. Considering the protein content to be the most important factor in determining the nutritive value of a plant, followed by the phosphorus, calcium, crude fiber, ash, and iron contents in this general order, it would appear that liming increased the nutritive value of the soybeans only slightly.

Since liming resulted in a definite increase in only the percent calcium but decidedly decreased the ash, boron, iron, manganese, and copper contents of the oats, the information in Table XI suggests that this soil treatment may have decreased the nutritive value of this crop.

For the alfalfa, liming increased the dry weights and the percentages of ash, protein, and calcium. Since these constituents are very important from the nutritional point of view, and since only iron, boron, and manganese were definitely decreased by liming, liming appeared to increase nutritive value of the alfalfa.

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Effects of Magnesium upon Plant Composition

The effects of liming with the calcium-magnesium carbonate mixture upon plant composition and nutrient production are expressed in Figures 16, 17, and 18. For all three crops, with but a few exceptions, very little difference could be seen between the effects of the two types of lime. The calcium content of the soybeans was slightly lower where the calcium-magnesium lime was applied than where the liming material was all calcium carbonate, but the greatest difference resulting from the two types of lime was in the magnesium content of the plants. There was a steady increase in the percent magnesium in the soybeans as the soil pH was raised with the mixed lime so that, at a pH of 6.8, the magnesium content of the soybeans was almost twice that obtained with the use of the calcium lime.

There were considerable variations between the effects of the two types of lime upon the copper, phosphorus, boron, and ash contents of the soybeans at each pH level, but since these variations were not consistent, these differences are probably of no importance. It is of interest to observe that the addition of magnesium to the liming material appeared to have no appreciable effect upon the uptake of phosphorus by the soybeans. The percent phosphorus in the plants was greatly decreased by the addition of the first increment of either kind of lime. Thus, these data for the soybeans do

not support the theory that increasing the supply of soil magnesium (especially when the soil is low in this element as this soil was) stimulates the uptake of phosphorus by the plant.

Similar observations may be made regarding the effect of magnesium on the composition of oats (Figure 17). Although, in the comparison of the two liming materials, the percentages of sodium, iron, copper, and phosphorus all varied considerably as the soil pH was increased, the net differences could not be traced to variations in kind of lime. This leads to the belief that the type of lime had no significant effects upon the concentration of these elements in the plants. The phosphorus content of the oats was considerably higher at a pH of 6.3 with the mixed lime than with the calcium lime, but most of this difference had disappeared at pH 6.8. Therefore, like the soybeans, the data on the oats crop do not support the idea that magnesium stimulates phosphorus uptake.

The only appreciable differences that can be seen between the effects of the two types of lime on the oats composition were in percentages of calcium and magnesium. As in the soybeans, the use of the calcium-magnesium mixture almost doubled the magnesium content of the oats and caused a small decrease in the calcium as compared to the effects of the calcium lime. The increase in magnesium in the oats

was almost a direct function of the percent magnesium saturation of the soil. Also, the mixed lime did not reduce the calcium content of the oats appreciably until the soil pH had been raised to 6.8.

The effects of increasing the supply of soil magnesium upon alfalfa composition may be determined from the graphs in Figure 18. The response of the alfalfa to the two different types of lime varied to a larger extent than did that of the other two crops. While calcium lime caused a slight decrease in the percent of ether extract, the mixed lime caused an increase. The increase in protein content was also more definite with the mixed lime. Variations in both the calcium and magnesium contents of the alfalfa were similar to those observed with the other crops.

The correlation coefficients between plant composition and the degree of magnesium saturation of the soil are listed in Table XII. The fact that very few of these "r" values were significant indicates that increasing the percent magnesium, and the total bases per 100 grams of dry material resulted in significant correlation coefficients. The percent magnesium and milliequivalents of total bases in the oats were also significantly correlated with the percent magnesium saturation of the soil. In the alfalfa, only the magnesium content was positively correlated with percent soil magnesium. In this crop the percentages of boron, phosphorus, iron, and manganese were significantly reduced by

TABLE XII

Correlation Coefficients Between Percent Magnesium
Saturation of the Soil and Plant Composition

Chemical constituent	"r" Values for:		
	Soybeans	Oats	Alfalfa
Ash	-0.0752	-0.0276	-0.2389
Crude Fiber	0.0629	0.1302	0.2274
Ether Extract	0.1366	0.0948	0.0482
Protein	0.0284	0.0400	0.1887
N-free Extract	-0.0492	-0.0772	-0.0417
Potassium	-0.1658	-0.1176	-0.0788
Sodium	-0.0110	0.1048	0.0606
Boron	-0.0151	-0.1684	-0.2963*
Phosphorus	-0.2146	-0.0694	-0.3027*
Iron	0.0454	-0.1688	-0.2639*
Magnesium	0.6450**	0.6337**	0.5088**
Manganese	-0.2671*	-0.0958	-0.2424*
Calcium	0.0170	0.1897	-0.1986
Copper	0.0284	-0.1450	0.2297
M.e. bases per 100 grams	0.2479*	0.4243**	-0.0521

* Significant at 5% level

** Significant at 1% level

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applications of magnesium. The "r" values were negative and significant at the 5% level. The negative value observed for phosphorus content definitely contradicts the proposed positive relationship between soil magnesium supply and phosphorus uptake by the plant.

Because of the manner in which the coefficient of likelihood was calculated, it was impossible to determine L values for the effects of magnesium treatments on plant composition. These effects are included in the listing of L values in Table X, so they contributed to the significance of many of those values. Also, since all sources have indicated that increasing the magnesium supply of the soil had only minor effects on plant composition, no summary table was prepared. The conclusions stated in Table XI serve this purpose with the exception that increasing soil magnesium resulted in an increase of magnesium in the plant tissue.

Effects of Soil Phosphorus upon Plant Composition

The effects of increasing the supply of available soil phosphorus upon the composition of soybeans are expressed by the graphs in Figure 19. In this and the following figures which express the relationship between the supply of soil phosphorus or potassium and plant composition, care must be used in interpreting the effects of the addition of the

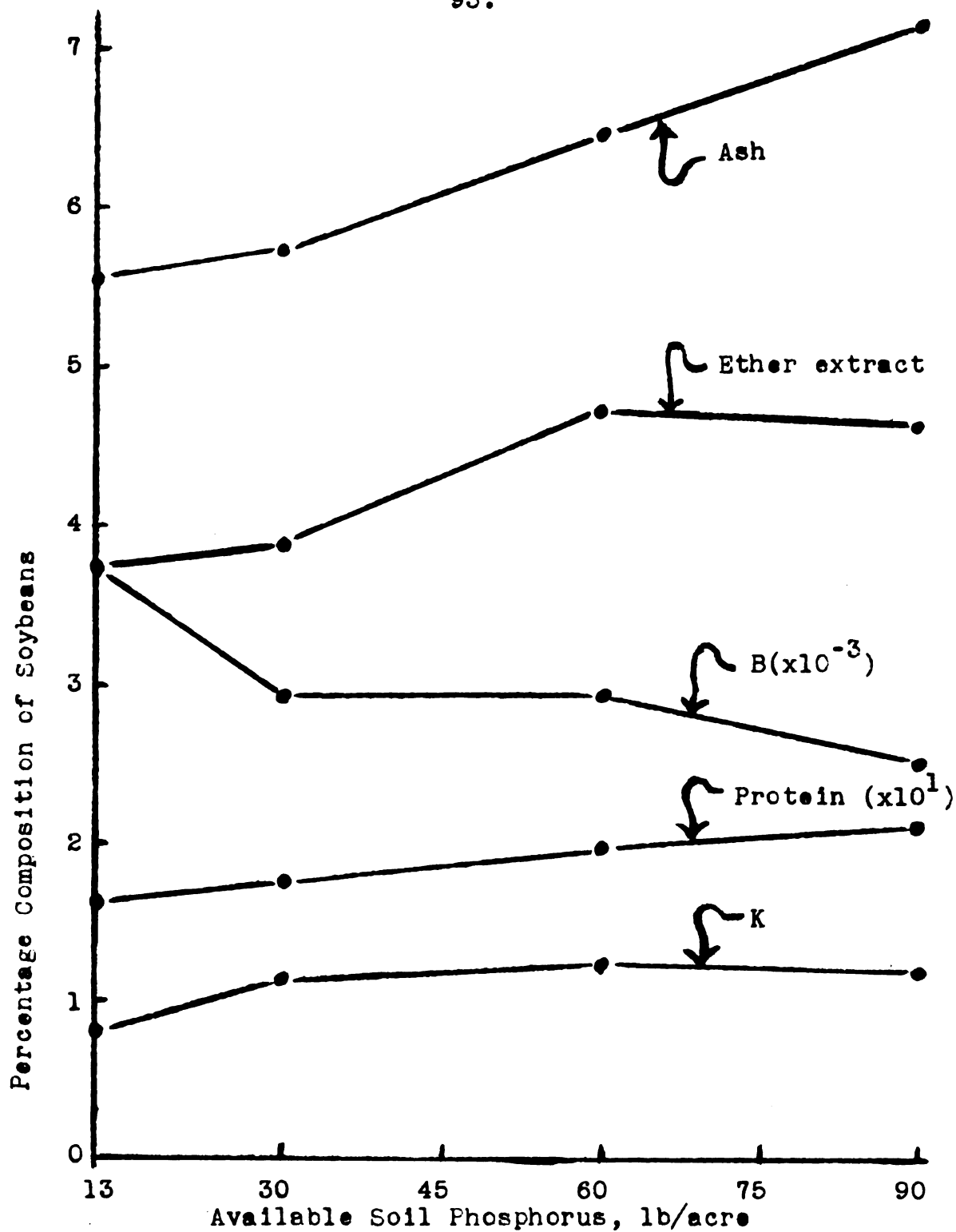


Figure 19. Effect of Available Soil Phosphorus upon Percentage Composition of Soybeans.

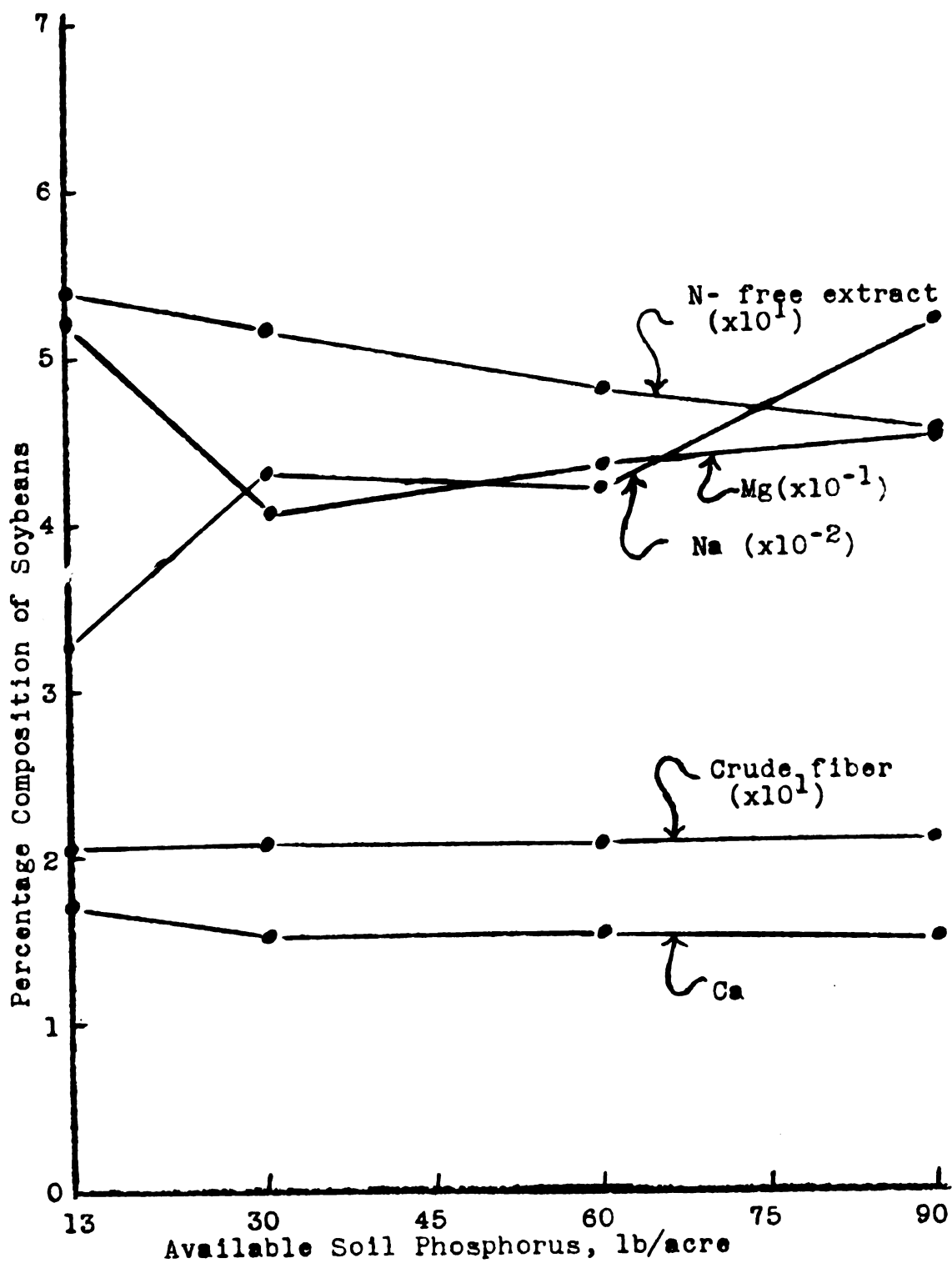


Figure 19. (continued)

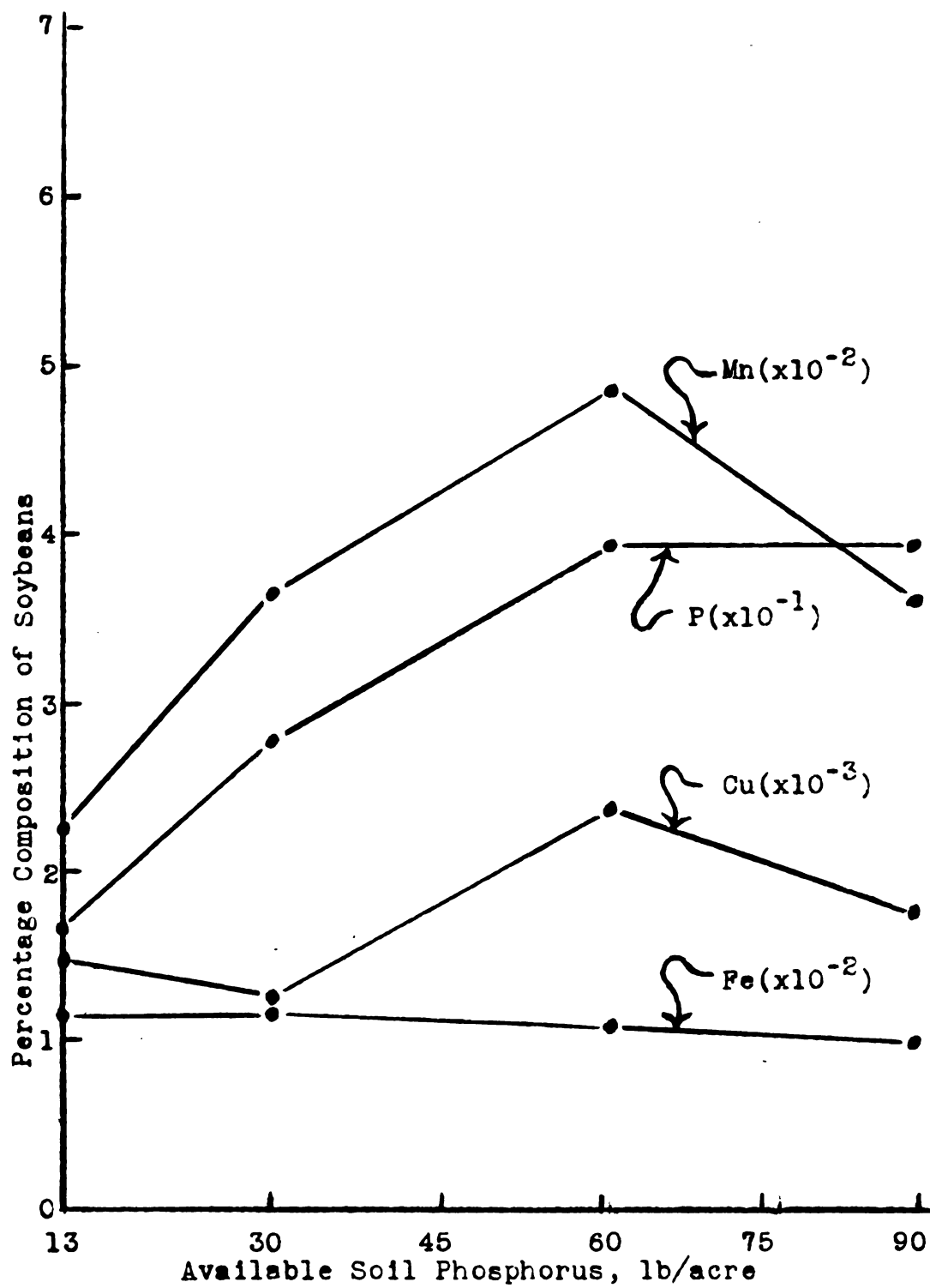


Figure 19. (continued)

first increments of the fertilizers. These changes express the effects of the addition of the first increments of both the phosphorus and potassium fertilizers, not just one of them alone, since there was no treatment in this experiment in which phosphorus was added to the soil without potassium, or vice versa. Thus, in this range, these graphs represent the combined effects of the two nutrients.

Increasing soil phosphorus resulted in rather large increases in the percent ash, sodium, ether extract, and phosphorus in the soybeans. Definite decreases occurred in percentages of boron and N-free extract. Protein and magnesium (at phosphorus levels above 30 pounds per acre) showed a slight but steady increase, while it appeared that the crude fiber, potassium (above the 30 pound per acre phosphorus level), calcium, and iron contents were not influenced by phosphorus fertilization. The percentage of both manganese and copper reached a maximum at the 60 pound per acre level of phosphorus, then suddenly decreased, indicating that the 60 pound per acre level was optimum for the uptake of these two minor elements. The noticeable decreases in the calcium and magnesium contents and the similar increase in potassium content that occurred upon raising soil phosphorus from 13 to 30 pounds per acre probably resulted mainly from the potassium fertilizer that was added at the same time instead of from the phosphorus fertilizer, since higher levels of soil phosphorus failed to alter the concentration of these

bases appreciably.

The effects of phosphorus fertilization upon the composition of oats are shown graphically in Figure 20. Those materials which increased in concentration as a result of increasing the supply of soil phosphorus included N-free extract, calcium, phosphorus, magnesium, and manganese. Those which decreased were iron, copper, protein, and ash. The percentages of crude fiber, ether extract, potassium, sodium, and boron were either fairly constant, or varied in no regular manner. Therefore, these results were contrary to the general belief that phosphorus fertilization increases the protein content of a plant but decreases the carbohydrate content. Although the total changes in these two constituents were small, nevertheless, they were very consistent, indicating that these trends may be significant. However, it should also be recognized that an increase in N-free extract content does not necessarily indicate a similar increase in carbohydrates since this chemical fraction contains other constituents as well.

The fact that phosphorus fertilization increased the uptake of the three principal divalent cations, calcium, magnesium, and manganese, may be of some significance. However, increasing soil phosphorus caused a decrease in the uptake of calcium and magnesium up to the 60 pound per acre phosphorus level. Then the addition of the last increment of phosphorus resulted in large increases in the uptake of

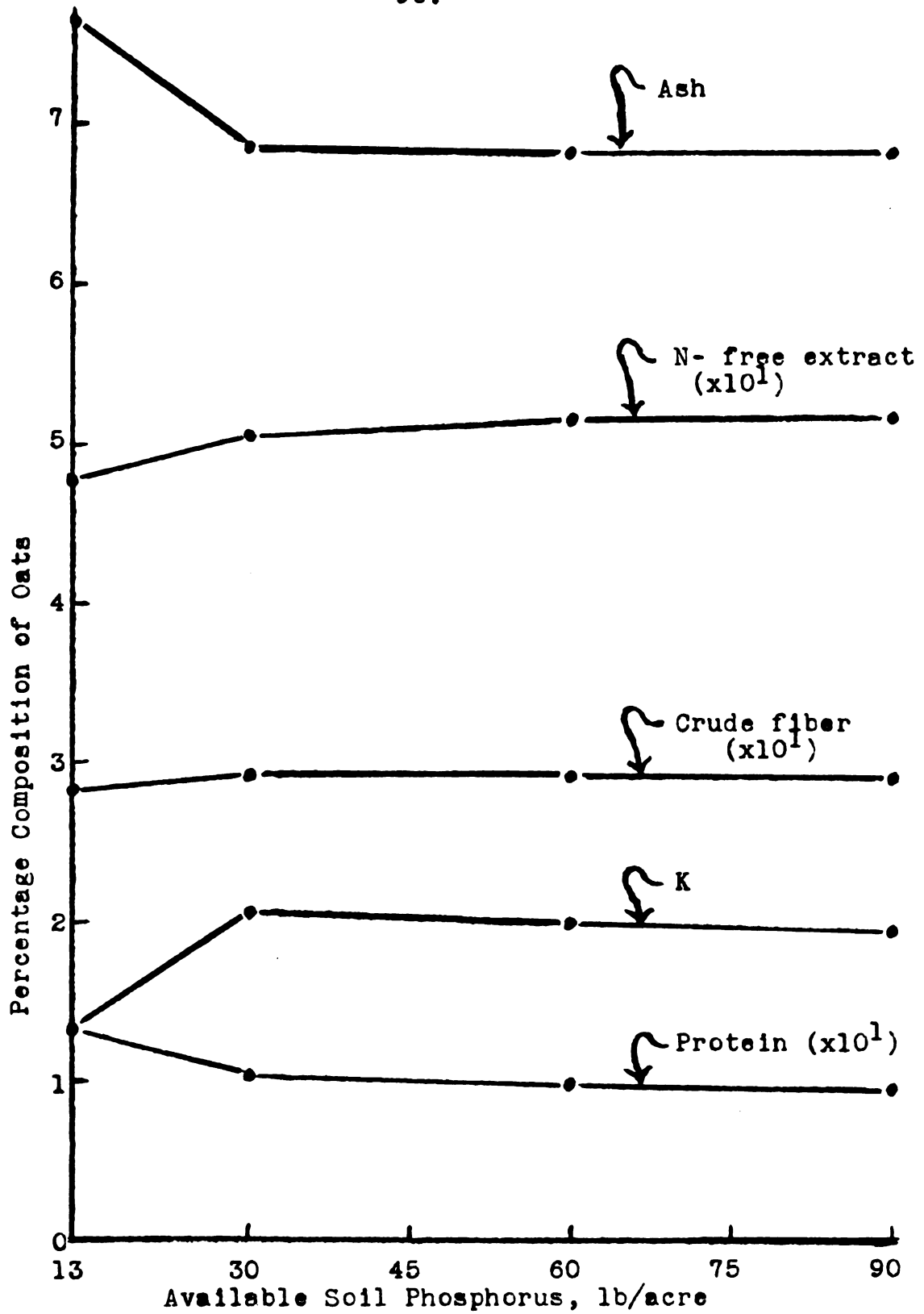


Figure 20. Effect of Available Soil Phosphorus upon Percentage Composition of Oats.

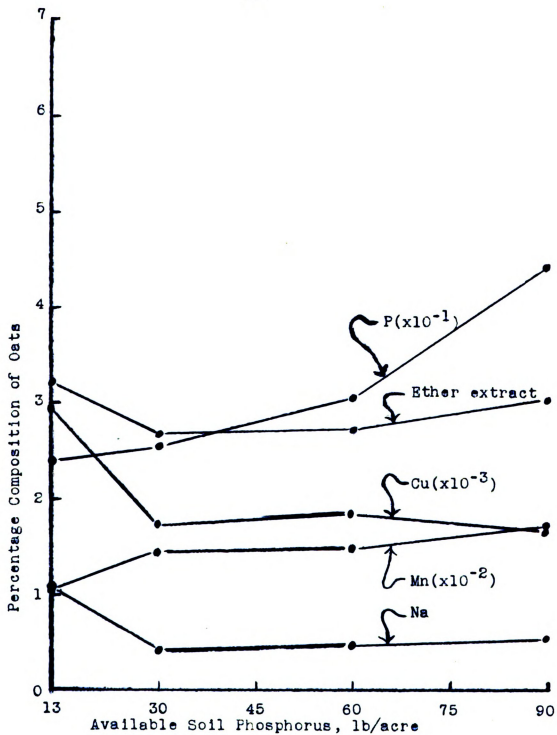


Figure 20. (continued)

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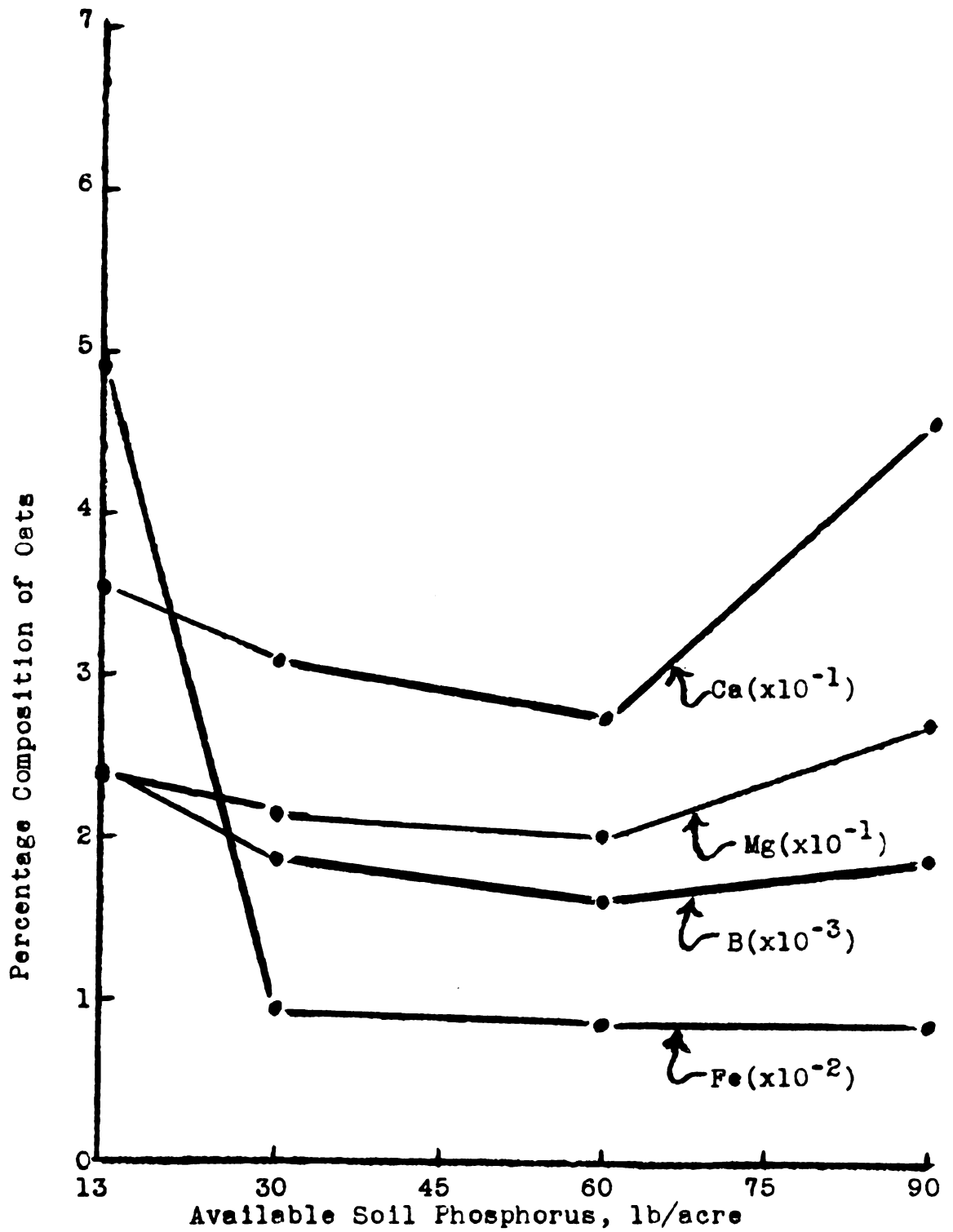


Figure 20. (continued)

these bases. If magnesium were necessary for the utilization of phosphorus by the plant, this rapid increase in magnesium content should have occurred with the addition of the first increment of phosphorus rather than at higher phosphorus levels. Thus, these data do not support the proposed magnesium-phosphorus relationship.

In Figure 21 are presented graphs representing the changes in the composition of the alfalfa that occurred upon applying increasing amounts of phosphorus to the soil. The ash, phosphorus, and iron concentrations were increased but the percent sodium, N-free extract, and copper decreased slightly. Very few of these changes in plant composition were large, so significance is questioned. The increase in the phosphorus content of the alfalfa as a result of phosphorus fertilization was much less definite than it was with the other two crops. It might be observed that these graphs suggest no relationship between magnesium and phosphorus.

The correlation coefficients between the level of available soil phosphorus and plant composition are presented in Table XIII. Significant positive correlations were found for the percent ash, crude fiber, ether extract, protein, potassium, sodium, phosphorus, and copper in the soybeans. The percent N-free extract gave a highly significant negative correlation. It is somewhat surprising that the

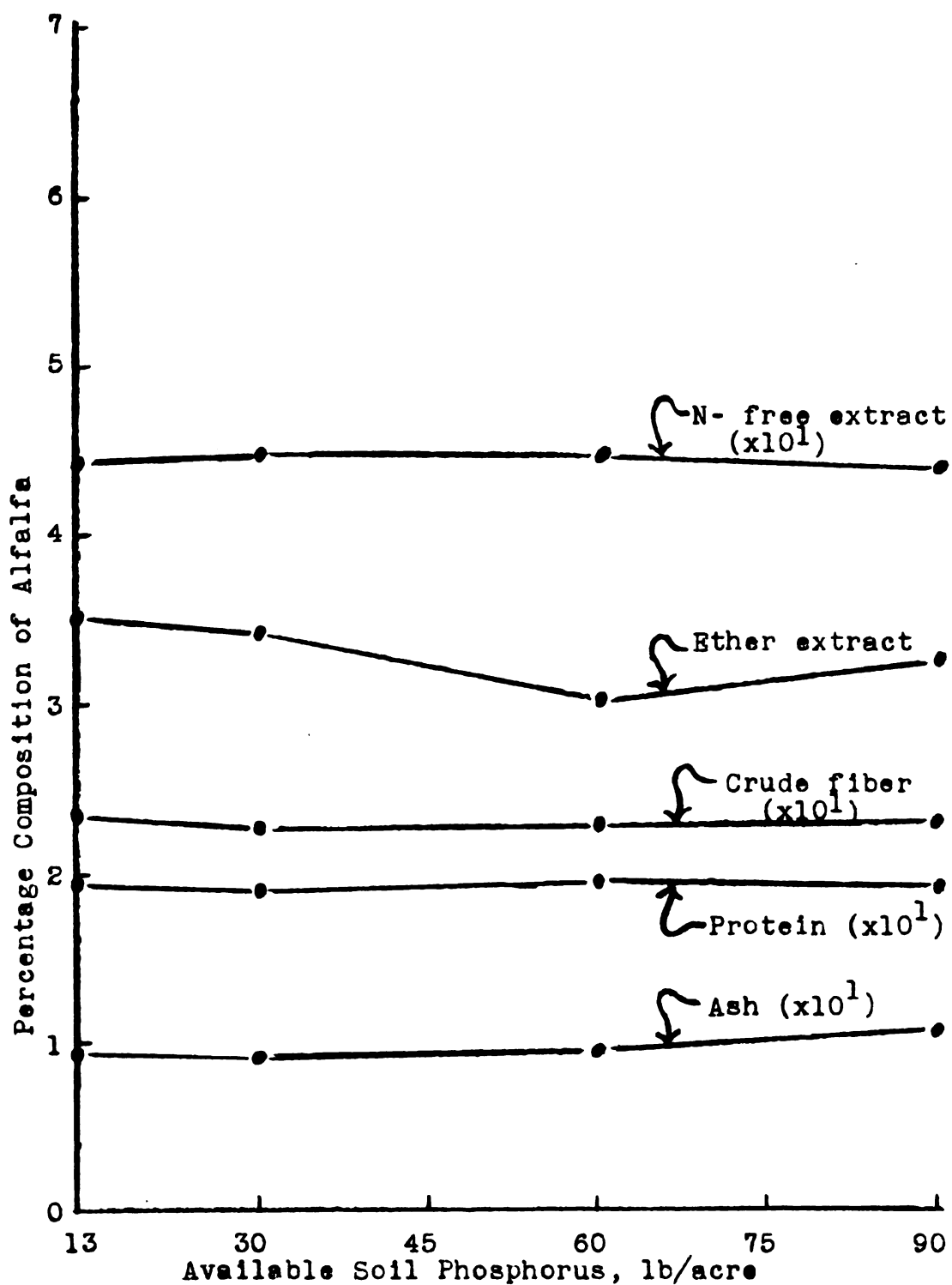


Figure 21. Effect of Available Soil Phosphorus upon Percentage Composition of Alfalfa.

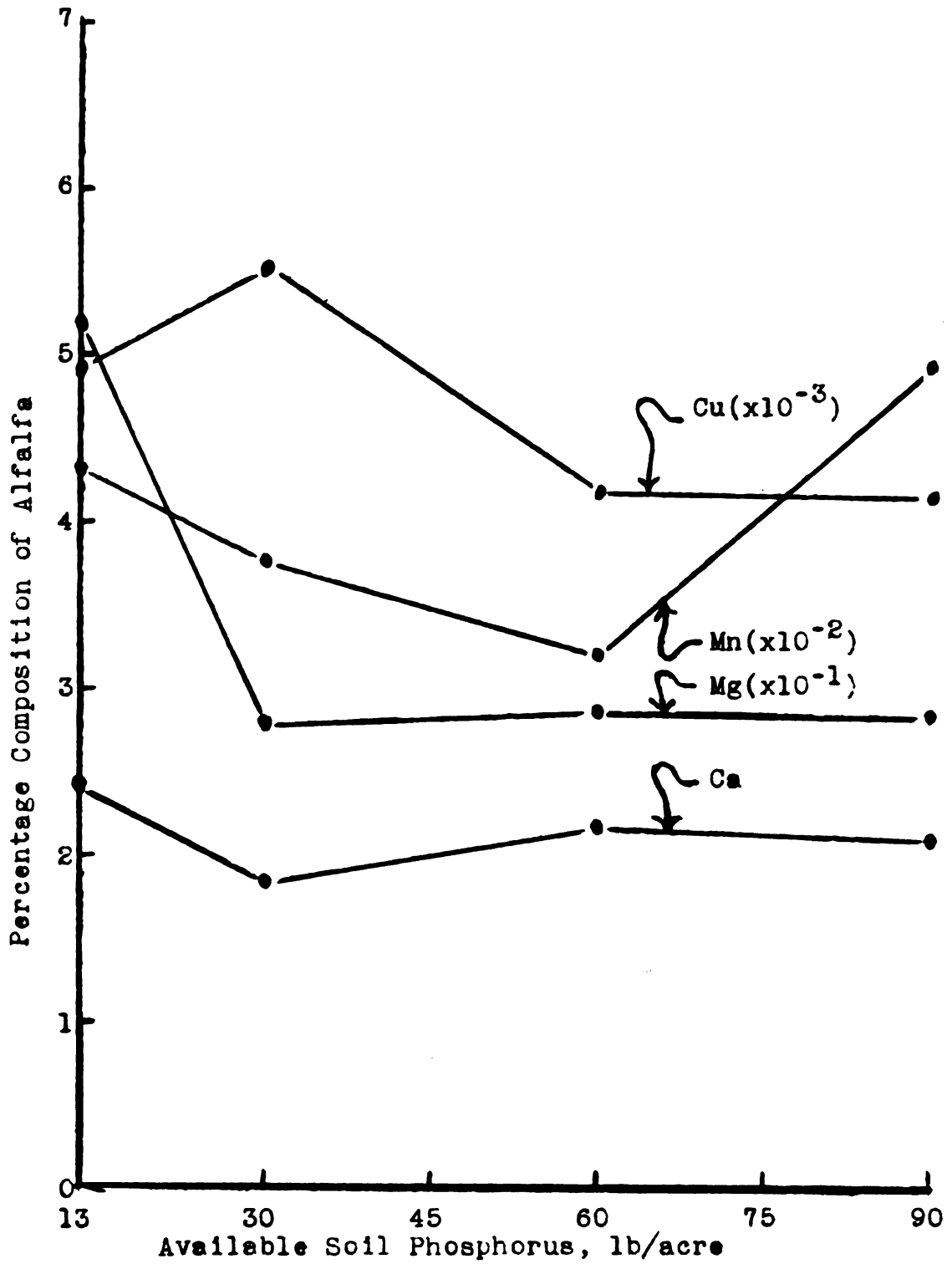


Figure 21.(continued)

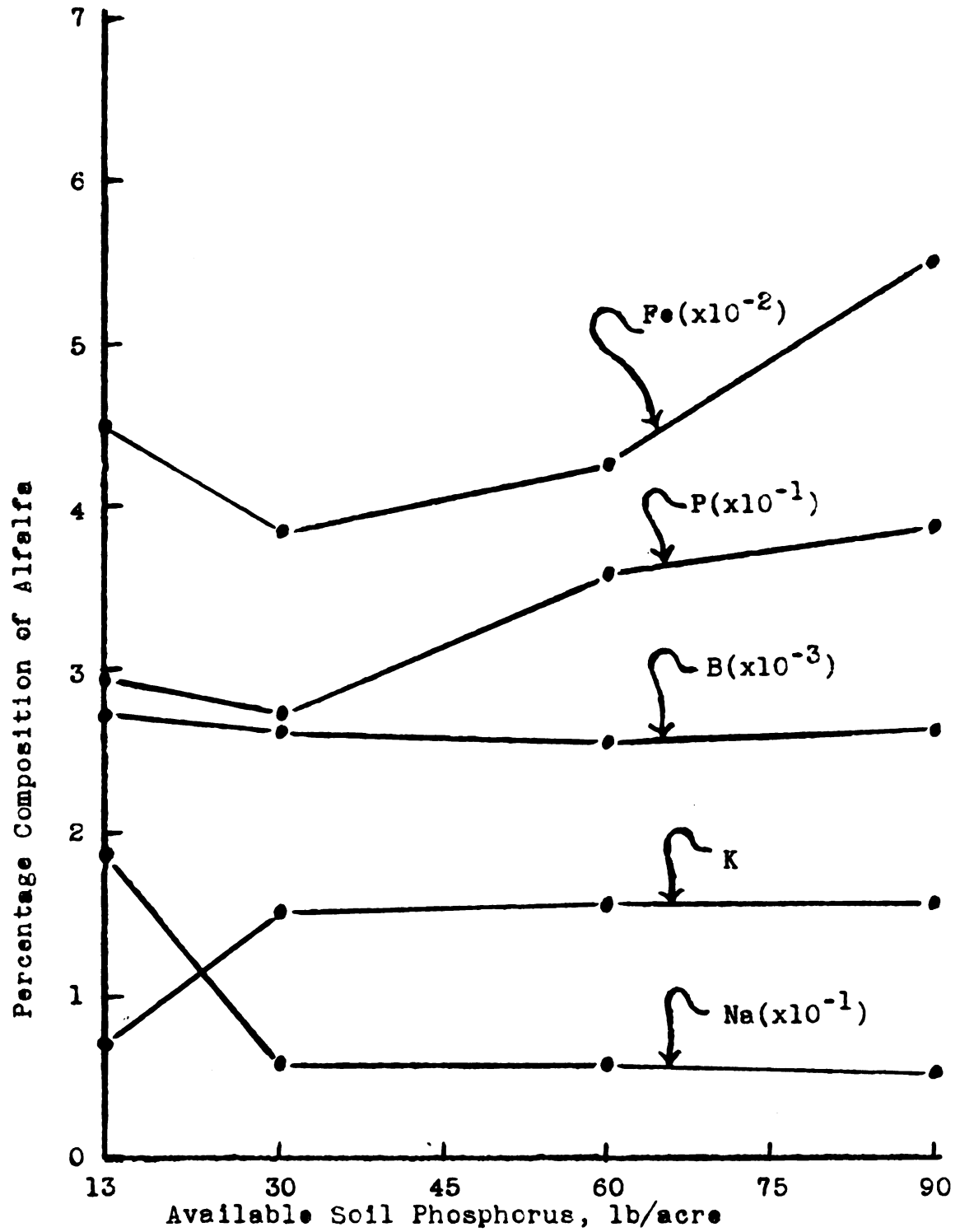


Figure 21. (continued)

TABLE XIII

Correlation Coefficients Between Supply of Available Soil
Phosphorus and Plant Composition

Chemical constituent	"r" Values for:		
	Soybeans	Oats	Alfalfa
Ash	0.8062**	0.0010	0.2619*
Crude Fiber	0.2563*	-0.0165	0.0103
Ether Extract	0.3381**	-0.0457	-0.1990
Protein	0.8130**	-0.6328**	-0.0221
N-free Extract	-0.6872**	0.4892**	-0.1782
Potassium	0.3245**	0.0830	0.2265
Sodium	0.4246**	-0.6117**	-0.2784*
Boron	-0.0459	-0.2286	-0.0507
Phosphorus	0.3811**	0.6616**	0.3389**
Iron	0.1870	-0.2674*	0.2961*
Magnesium	0.0005	0.1949	-0.2401*
Manganese	0.0478	0.1152	0.0420
Calcium	-0.0722	0.3341**	-0.0063
Copper	0.2687*	-0.2245	-0.3397**
M.e. total bases per 100 grams	-0.0434	0.1114	0.0154

* Significant at 5% level

**Significant at 1% level

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sodium and potassium contents in the plant showed a relationship to the level of soil phosphorus. It may be observed that the "r" values for both ash and protein were extremely high, especially considering the number of treatments involved. Since the percentages of these two constituents, plus phosphorus, gave highly significant correlations, it appears that the phosphorus fertilization of the soybeans definitely increased the nutritive value of the plants.

- The "r" values for the oats crop listed in Table XIII indicate that adding phosphorus to the soil increased the percent N-free extract, phosphorus, and calcium in the plant, but decreased the percent protein, sodium, and iron. Comparison of these results to those obtained with the soybeans demonstrates some wide differences in the responses of the two kinds of plants to the same soil treatment. This was particularly true of the protein, N-free extract, and sodium contents of the two plants. Therefore, it is doubtful that phosphorus fertilization resulted in increasing the nutritive value of the oats.

Those constituents in the alfalfa plants that showed significant positive correlations to the level of available soil phosphorus were ash, phosphorus, and iron. Those showing negative correlations were sodium, magnesium, and copper. Thus, the values listed in Table XIII suggested that phosphorus fertilization probably only slightly

increased the nutritive value of the alfalfa. It is interesting to observe that the "r" value relating plant magnesium to soil phosphorus had negative significance, just as occurred with the correlation coefficient relating soil magnesium supply to plant phosphorus content.

In calculating the coefficients of likelihood for both phosphorus and potassium fertilization, it was necessary to omit the composition of the plants grown at the lowest levels of these two nutrients ("0" treatments). Therefore, these L values indicate only the variation in plant composition between the three higher levels of both fertilizers.

The L values for phosphorus fertilization are presented in Table XIV. Significant variations between the various levels of soil phosphorus were found for the percent protein, boron, phosphorus, sodium, iron, calcium, and copper in the soybeans. Other sources of information in this paper have indicated that the variations in iron and boron content were in a negative direction.

In the oats plants, significant variations in the percent iron and copper were produced by phosphorus fertilization. Much of the variation in the other constituents suggested by the graphs (Figure 17) and correlation coefficients must have occurred in raising the level of available phosphorus to 30 pounds per acre since such variations were not significant at the three higher phosphorus levels,

TABLE XIV

Coefficients of Likelihood for Variations in Plant
Composition Resulting from Phosphorus Fertilization of
the Soil

Chemical constituent	L Values for:		
	Soybeans	Oats	Alfalfa
Ash	0.9691	0.9633	0.5321**
Crude Fiber	0.9143	0.9274	0.9438
Ether Extract	0.9850	0.9999	0.6090**
Protein	0.8464**	0.9438	0.8849*
N-free Extract	0.9958	0.9653	0.7925**
Potassium	0.9432	0.9913	0.9968
Sodium	0.8073**	0.9987	0.9976
Boron	0.7750**	0.9398	0.9489
Phosphorus	0.6813**	0.9772	0.8600*
Iron	0.6649**	0.7220**	0.8042**
Magnesium	0.9604	0.9793	0.9879
Manganese	0.9403	0.9947	0.8987*
Calcium	0.8206**	0.9101	0.8550*
Copper	0.7300**	0.8969*	0.9903
M.e. total bases per 100 grams	0.7390**	0.9349	0.8379**

* Significant at 5% level

**Significant at 1% level

according to this method of statistical analysis.

The L values in Table XIV indicate that the percentages ash, ether extract, protein, N-free extract, phosphorus, iron, manganese, and calcium, and the total bases per 100 grams of alfalfa varied significantly between the three highest levels of soil phosphorus used. The variations in phosphorus content were significant at only the 5% level, indicating that the response of alfalfa to phosphorus fertilization in regard to this constituent was less decisive than it was with the oats and soybeans.

A summary of the effects of phosphorus fertilization upon the growth and composition of the soybeans, oats, and alfalfa plants is presented in Table XV. The differences in the response of the three crops may be ascertained from a study of this table. Since the percent ash, protein, and phosphorus in the soybeans definitely increased as a result of phosphorus fertilization, it may be concluded that this soil treatment definitely increased the nutritive value of this crop. In the oats, the phosphorus and calcium contents were increased, but the percent protein and iron was decreased by applying phosphorus to the soil, so it is doubtful that this practice resulted in making this crop more nutritious. Since the concentration of no major nutritive constituent in the alfalfa was decreased by phosphorus fertilization of the soil, and since the ash, phosphorus, and iron contents were all increased, this soil treatment

Summary of Effects of Phosphorus Fertilization of the Soil upon Plant Growth and Composition

Increase		Decrease		No Effect ¹	
Soybeans	Oats	Alfalfa	Soybeans	Oats	Alfalfa
Dry weight*	Dry weight***	Ash**	N-free ex-tract**	Ash*	Ether ex-tract*
				Potas-sium	Crude fiber
Ash***	N-free ex-tract**	Potas-sium*	Boron**	Pro-tein**	N-free ex-tract*
					Magnes-ium
Crude fiber*	Phospho-rus***	Phospho-rus**	Iron*	Iron**	Sodium**
					Mangan-ese
Ether ex-tract**	Magnes-ium*	Iron**		Copper*	Copper*
					Calcium
Protein ***	Mangan-ese*				Boron
					Magnes-ium
Sodium ***	Calcium **				Mangan-ese
					Calcium
Phospho-rus***					
Copper**					

1 Variations were of no significance.
* Variations were of questionable significance.
** Variations were moderately significant.
*** Variations were definitely significant.

appeared to have increased the nutritive value of the alfalfa also. It may be observed from Table XV that the response of the three crops to phosphorus fertilization varied widely. Phosphorus was the only plant constituent which varied in a similar manner in all three crops.

Effects of Soil Potassium upon Plant Composition

The effects of increasing the supply of soil potassium upon the chemical composition of soybeans are presented in the graphs in Figure 22. Increases occurred in the contents of ash, sodium, potassium, and manganese, while the percentages of iron, magnesium, and N-free extract decreased. The level of soil potassium appeared to have no effect upon the percent crude fiber in the soybeans. Except for the addition of the first increment of potassium chloride, at which time phosphorus was also applied to the soil, increasing soil potassium caused no appreciable change in the percent phosphorus, boron, copper, calcium, or protein in the plant material. The ether extract content was slightly decreased by the addition of potassium.

The results show that potassium fertilization did not increase the N-free extract or decrease the protein content of the soybeans. Also, above the 100 pound per acre level of potassium, there was a definite decrease in the ether extract fraction. Thus, this is further evidence that potassium fertilization did not promote the formation of

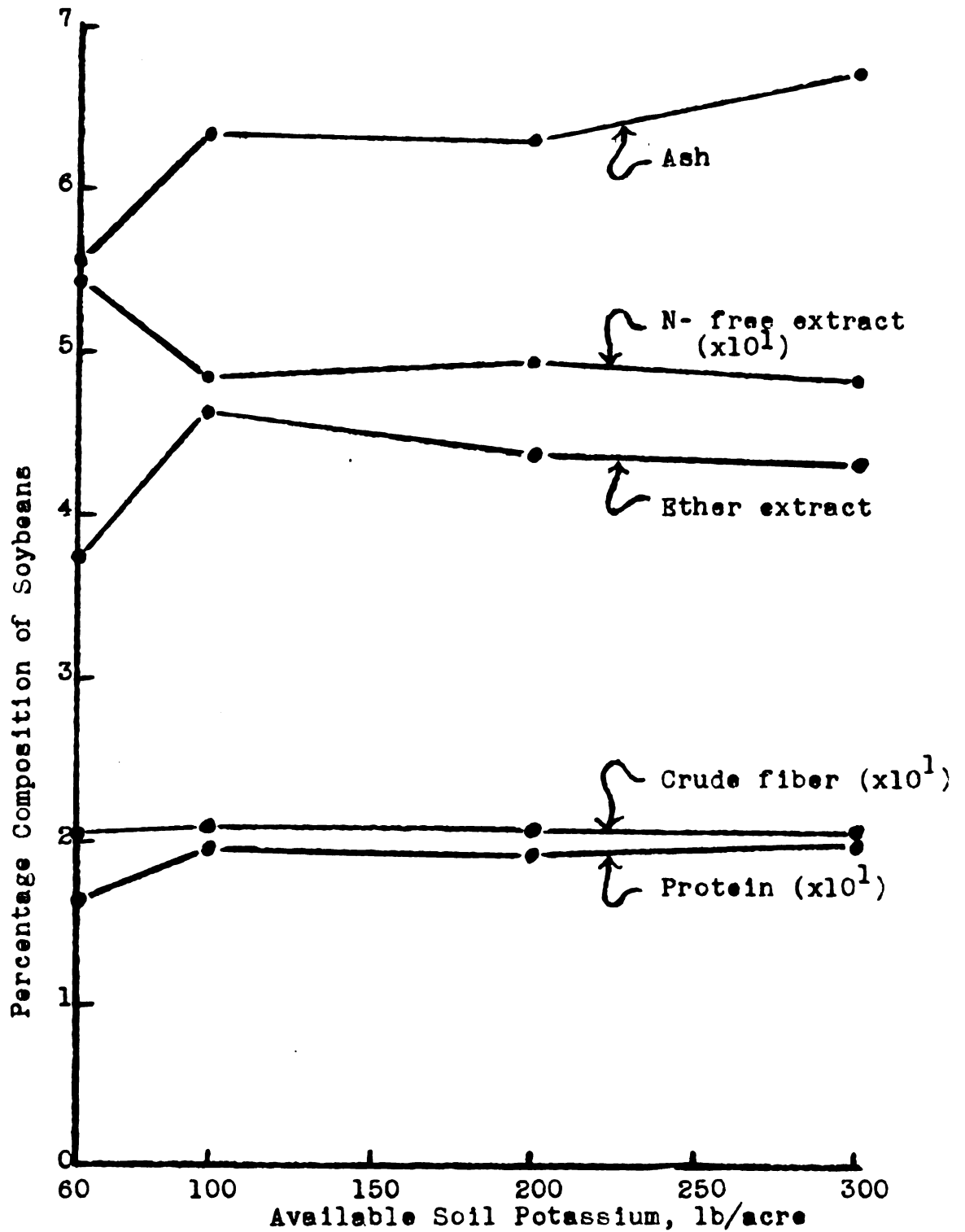


Figure 22. Effect of Available Soil Potassium upon Percentage Composition of Soybeans.

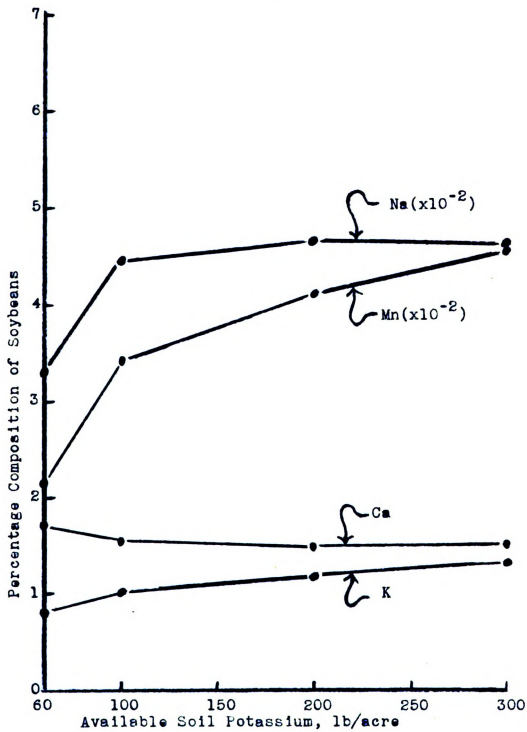


Figure 22. (continued)

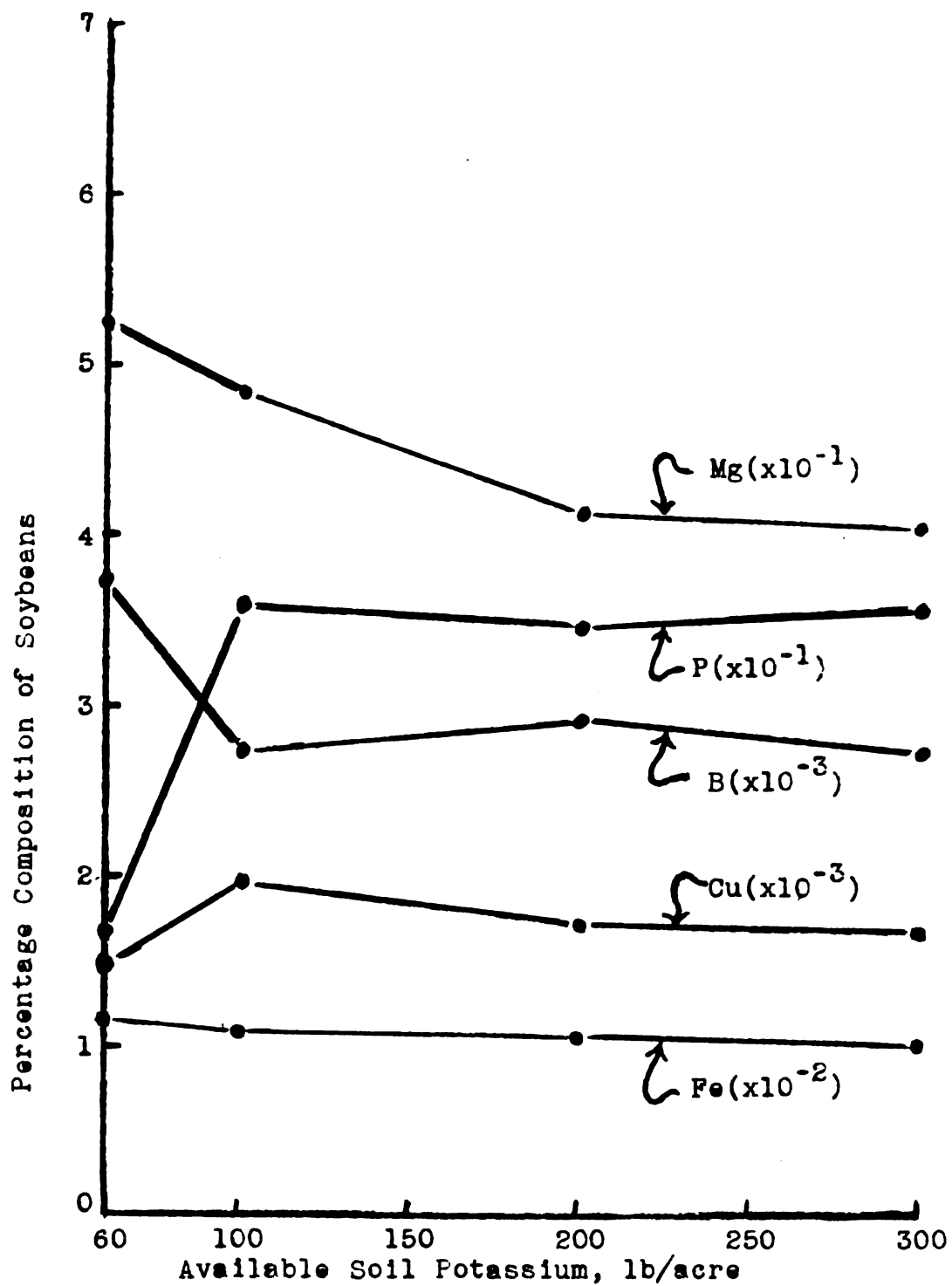


Figure 22. (continued)

carbonaceous materials as has been suggested (1, 37).

Some of the most striking changes shown by these results (Figure 22) were the increases that occurred in the potassium, ash, and manganese contents, and the steady decrease in magnesium content resulting from potassium fertilization. This last observation was expected since potassium fertilization had no appreciable effect upon total bases in the plant material. Therefore, since the percent potassium increased, the percent of some other base should decrease. The large increase in manganese content was quite unexpected, and is unexplainable.

The effects of potassium fertilization upon the composition of oats are shown in Figure 23. Potassium fertilization caused an increase in potassium and manganese, and definite decreases in iron, copper, sodium, and ether extract. Above the 100 pound per acre level of potassium, the percent ash increased, and N-free extract, crude fiber, protein, calcium, phosphorus, magnesium, and boron changed only slightly.

In most respects these graphs resemble those in Figure 22. As in the soybeans, the percent manganese increased directly with increased soil potassium. This treatment did not produce an increase in the carbonaceous fractions of the oats, nor did it decrease the protein content. The greatest difference between the response of these two crops

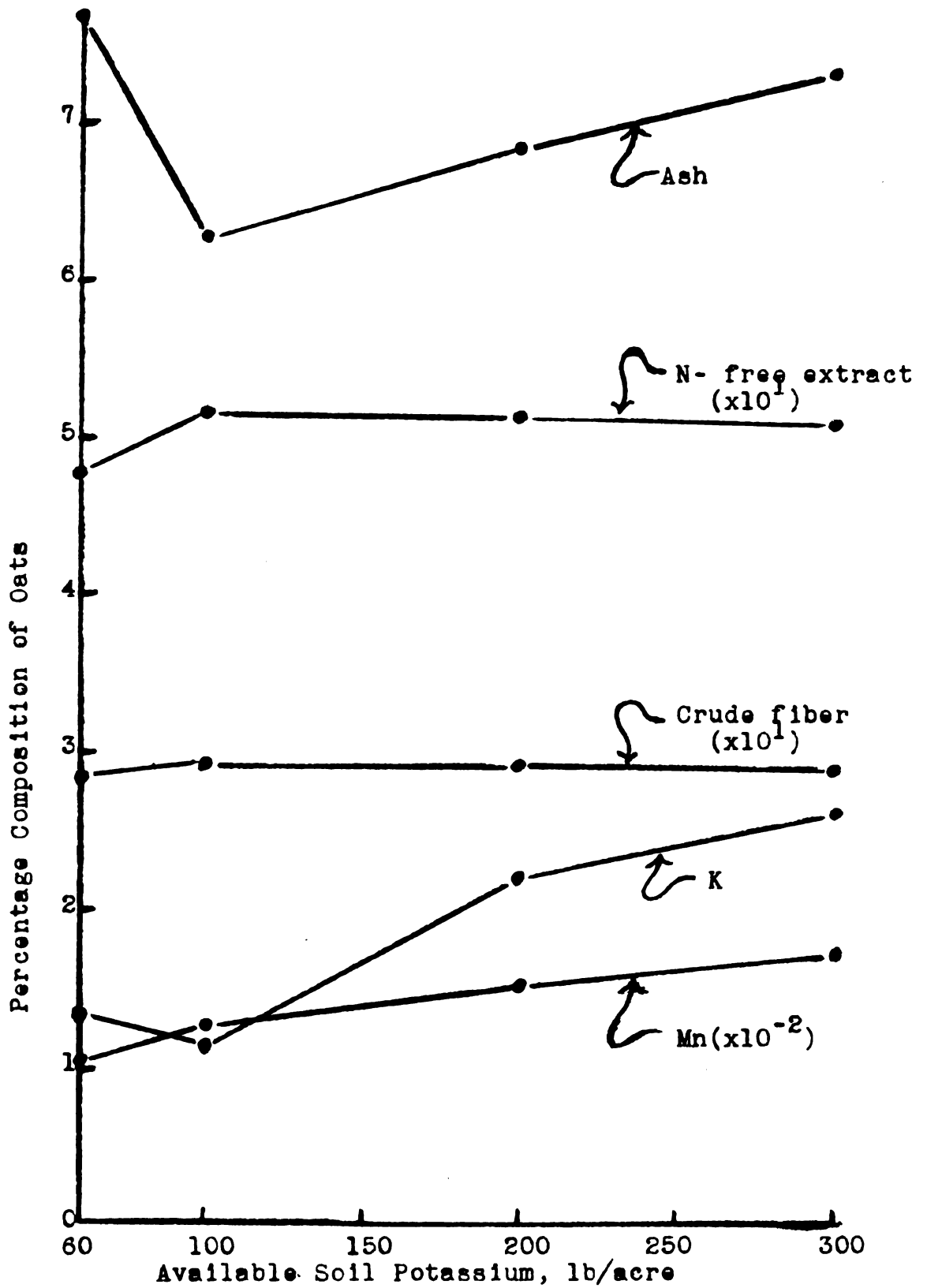


Figure 23. Effect of Available Soil Potassium upon Percentage Composition of Oats.

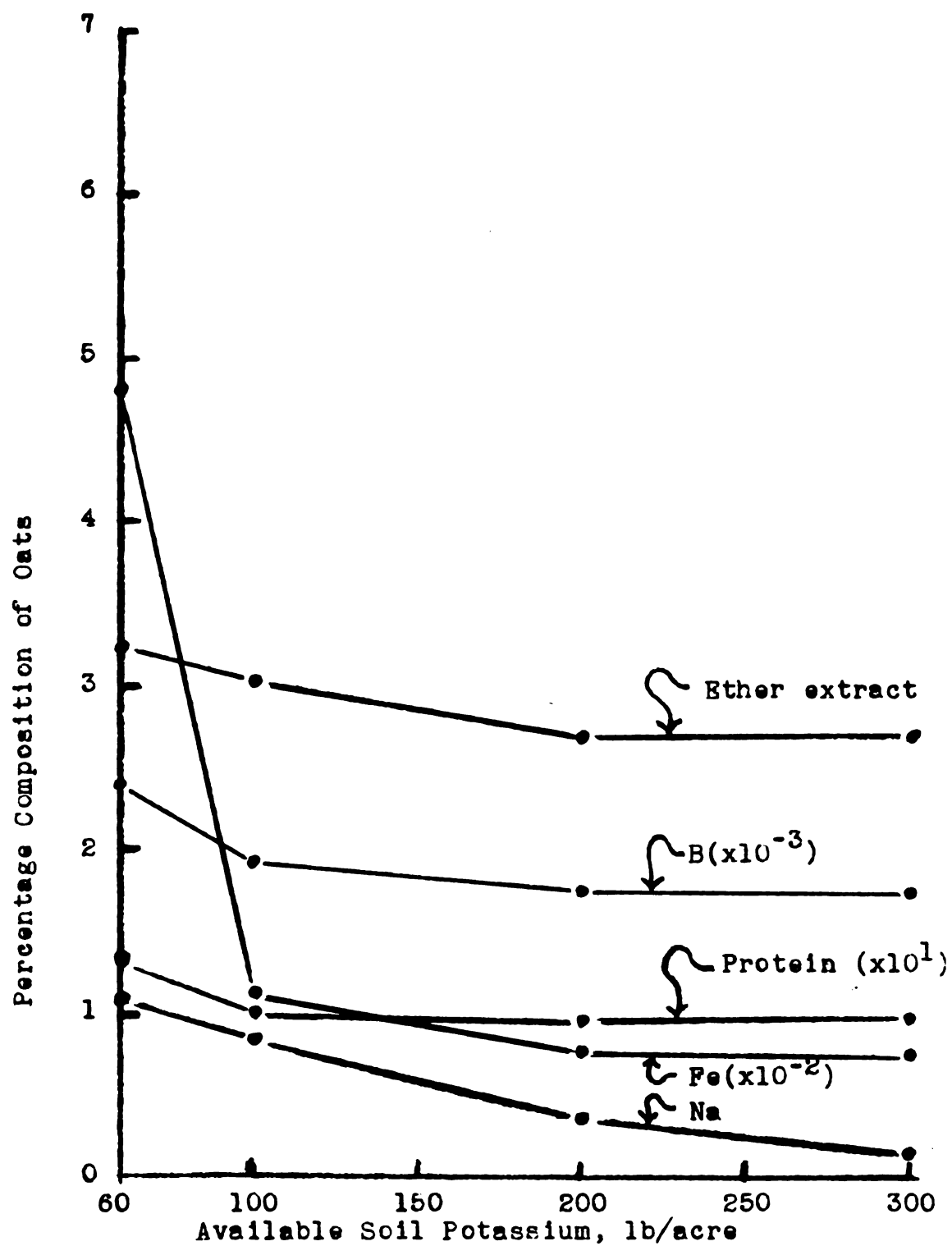


Figure 23. (continued)

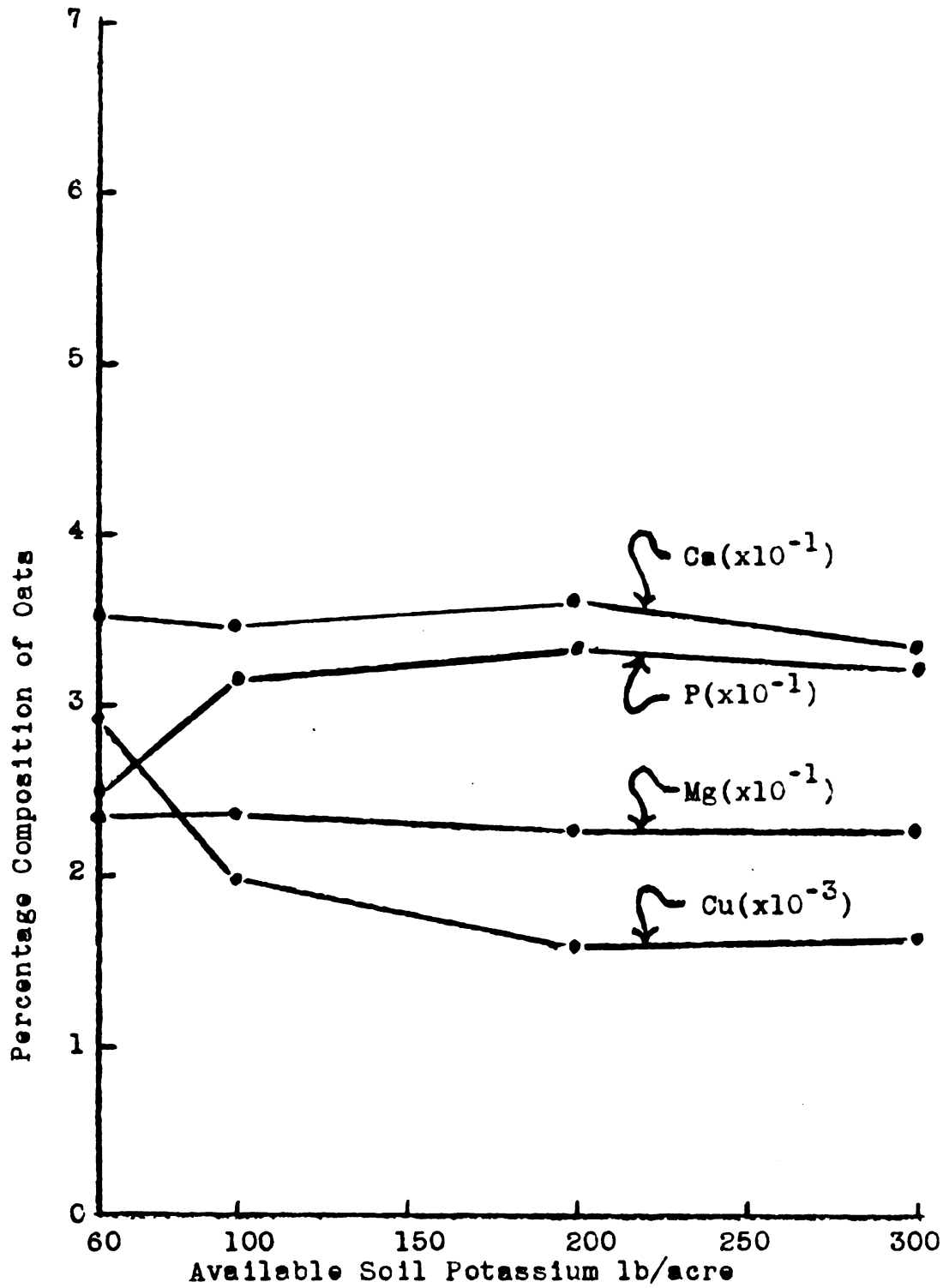


Figure 23. (continued)

was that, in the oats, the percent sodium, instead of magnesium, decreased as the percent potassium in the plant increased.

The graphs presented in Figure 24, relating the supply of soil potassium to alfalfa composition, indicate that increasing soil potassium resulted in increased percentages of ash and potassium, and decreased percentages of sodium, boron, phosphorus, magnesium, and calcium. It is interesting to note that this soil treatment decreased the uptake of the other three principal bases (sodium, magnesium, and calcium). It appeared to have only a small effect upon the uptake and formation of the feedstuff constituents.

The alfalfa crop appeared to resemble the other two crops so far as potassium fertilization was concerned. However, the percent manganese failed to show the definite increase observed with the other two crops. Also, both the sodium and potassium (as well as calcium) concentrations decreased whereas only one of them was decreased in each of the other two crops.

The correlation coefficients listed in Table XVI are a measure of the effects of potassium fertilization of the soil upon plant composition. For the soybean plants, it may be observed that this soil treatment resulted in plants significantly higher in percent ash and potassium, but lower in magnesium and protein. The exceedingly large "r" value

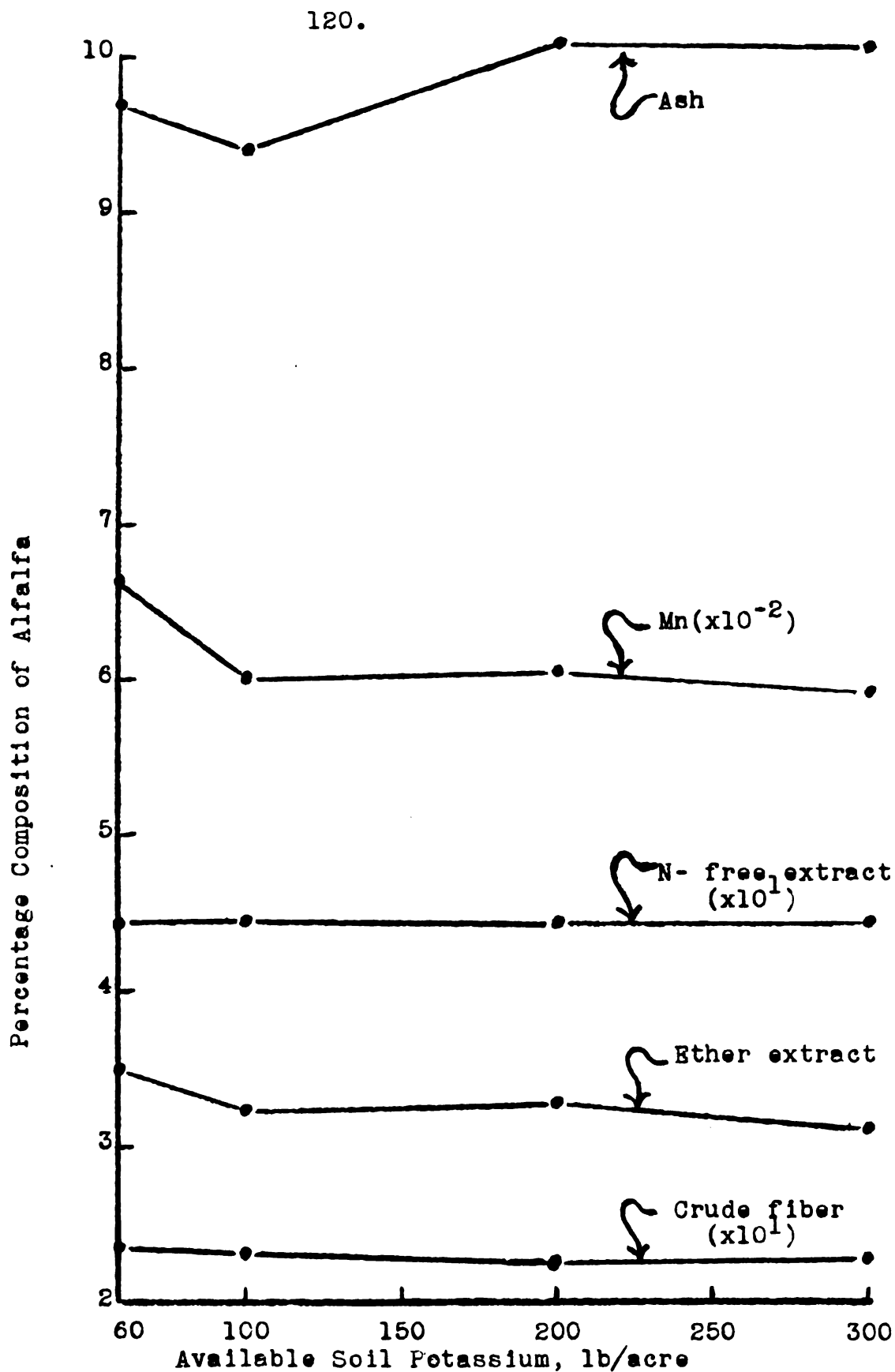


Figure 24. Effect of Available Soil Potassium upon Percentage Composition of Alfalfa.

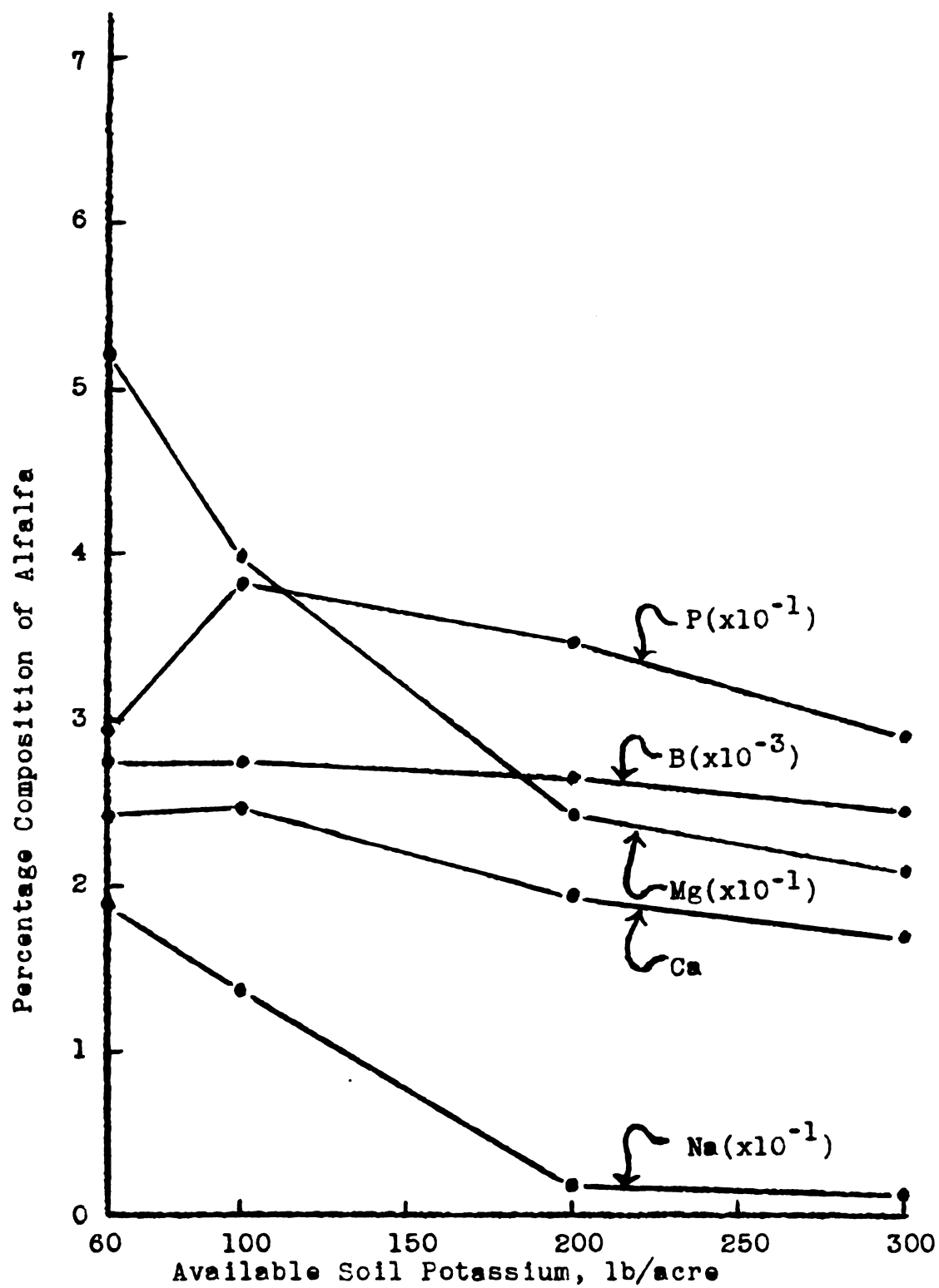


Figure 24. (continued)

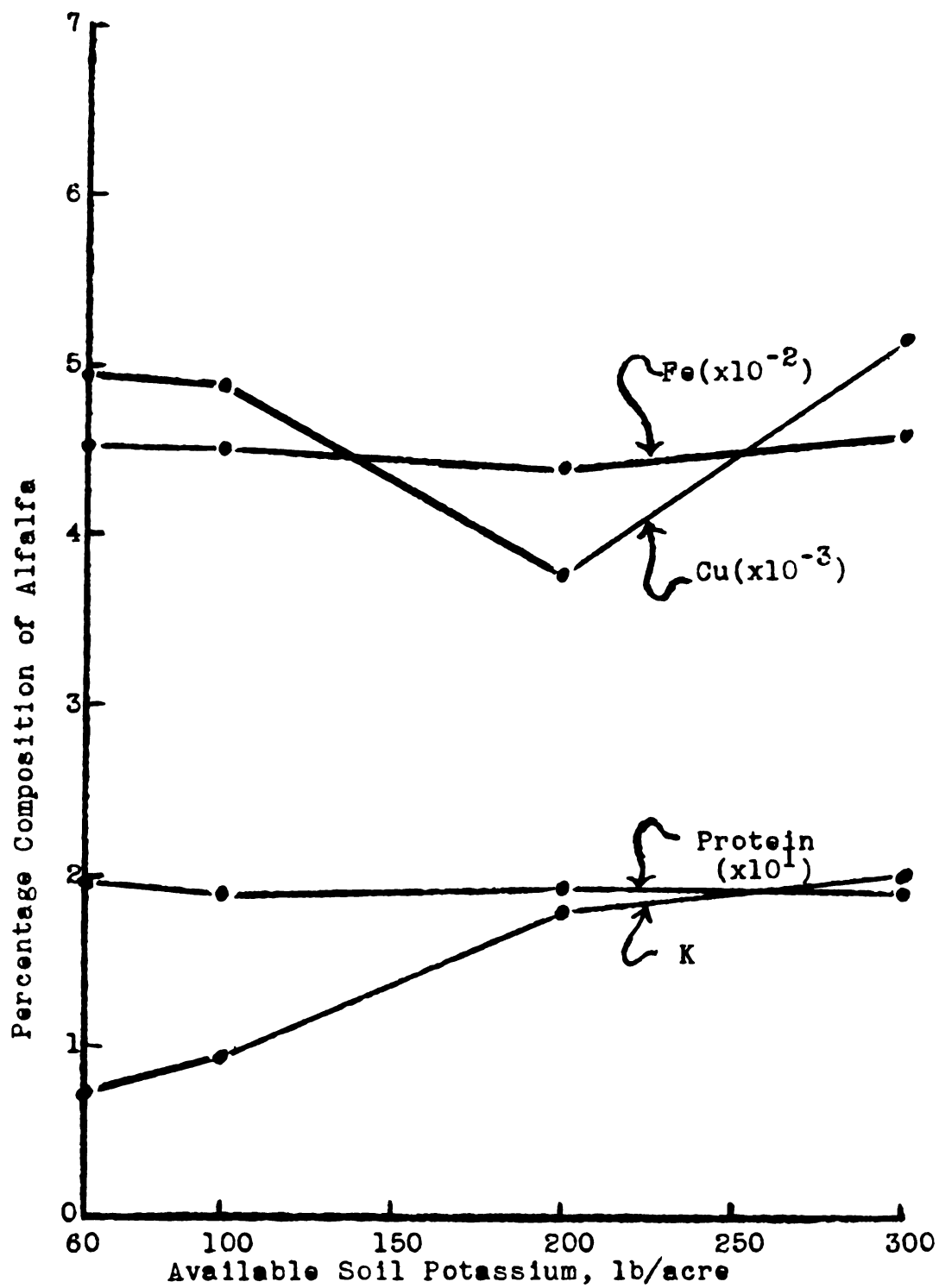


Figure 24. (continued)

TABLE XVI

Correlation Coefficients Between Percent Potassium Saturation of the Soil and Plant Composition

Chemical constituent	"r" Values for:		
	Soybeans	Oats	Alfalfa
Ash	0.3494**	0.0241	0.0278
Crude fiber	0.1012	0.0131	-0.3200*
Ether extract	-0.1950	-0.2412*	-0.1818
Protein	-0.2396*	-0.3083**	0.4599**
N-free extract	-0.2140	0.1714	-0.3175*
Potassium	0.8527**	0.8845*	0.6040**
Sodium	0.1856	-0.9103**	-0.6492**
Boron	-0.0198	-0.0873	-0.1296
Phosphorus	0.1291	0.1253	-0.1822
Iron	-0.1151	-0.2523*	0.0606
Magnesium	-0.2624*	-0.0283	-0.5508**
Manganese	0.0984	0.0499	-0.0096
Calcium	-0.0737	-0.0484	-0.5338**
Copper	-0.0824	-0.2611*	0.0851
M.e. total bases per 100 grams	-0.0535	0.0317	-0.3211*

* Significant at 5% level

**Significant at 1% level

for the potassium content of the plants showed that the percent potassium in the soybeans was almost a linear function of the supply of available soil potassium.

In the oats plants, potassium fertilization caused a significant increase only in the percent potassium, and decreases in the percentages of ether extract, protein, sodium, iron, and copper. As in the soybeans, the percent potassium in the oats showed a very high positive correlation to the level of soil potassium. However, the sodium content of this crop had an even higher negative correlation coefficient.

The correlation coefficients listed in Table XVI indicate that potassium fertilization significantly increased the percent protein and potassium in the alfalfa, but decreased percentages of crude fiber, N-free extract, sodium, magnesium, and calcium. The total bases per 100 grams of plant material were also significantly decreased. The "r" values for the alfalfa crop were quite similar to those of the other two crops. For example, very highly significant correlation coefficients were found between plant potassium and soil potassium for all three species. Also, the percent of at least one base in the plant was greatly reduced by potassium fertilization. Alfalfa differed from the other two crops in that this soil treatment resulted in increased protein formation in the plant, while it was decreased in the oats and soybean plants.

The coefficients of likelihood calculated for the variations in plant composition resulting from potassium fertilization are reported in Table XVII. As mentioned for the table of L values for phosphorus fertilization, the "0" treatment (60 pound per acre potassium level) was omitted in these calculations, so the values in Table XVII represent only the variations in plant composition resulting from the three highest levels of potassium in the soil.

In the soybeans, only the percent crude fiber, potassium, and iron showed significant variations in the plants grown at the three different potassium levels. However, the percent ash, crude fiber, potassium, sodium, and iron in the oats varied significantly. In the alfalfa, potassium fertilization yielded significant L values for the variations in the percentages of ash, protein, potassium, sodium, magnesium, and calcium.

The results of the statistical analyses of the data on the effects of potassium fertilization upon plant composition are summarized in Table XVIII. This table shows many similarities between the responses of the various crops to potassium fertilization. This practice increased the ash and potassium contents of all three crops. At the same time, the ether extract, iron, and copper contents tended to decrease in the soybeans and oats, but not in the alfalfa. In the soybeans, the magnesium content was decreased, but the sodium concentration was decreased in the oats. In

TABLE XVII

Coefficients of Likelihood for Variations in Plant
Composition Resulting from Potassium Fertilization
of the Soil

Chemical constituent	L values for:		
	Soybeans	Oats	Alfalfa
Ash	0.9389	0.5861**	0.6269**
Crude Fiber	0.8593*	0.7977**	0.9631
Ether Extract	0.9472	0.9999	0.9878
Protein	0.9931	0.9350	0.8749*
N-free Extract	0.9931	0.9521	0.9651
Potassium	0.7889**	0.4342**	0.5248**
Sodium	0.9938	0.8811*	0.1887**
Boron	0.9896	0.9930	0.9702
Phosphorus	0.9901	0.9606	0.9913
Iron	0.8540*	0.8372**	0.9292
Magnesium	0.9687	0.9996	0.7400**
Manganese	0.9292	0.9902	0.9913
Calcium	0.9999	0.9654	0.8342**
Copper	0.8998	0.9096	0.9049
M.e. total bases per 100 grams	0.9950	0.9847	0.8828*

*Significant at 5% level

**Significant at 1% level

TABLE XVIII

Summary of Effects of Potassium Fertilization of the Soil upon Plant Growth and Composition

Increase		Decrease			No Effect ¹			
Soybeans	Oats	Alfalfa	Soybeans	Oats	Alfalfa	Soybeans	Oats	Alfalfa
Ash**	Dry weight*	Ash*	Dry weight*	Ether ex-tract**	Crude fiber*	Crude fiber	Crude fiber	Dry weight
Potas-sium***	Ash**	Pro-tein*	Ether ex-tract*	Sodium ***	Sodium ***	Protein	Protein	Ether ex-tract
Sodium*	Potas-sium***	Potas-sium***	Iron*	Iron**	Boron*	N-free extract	N-free extract	N-free extract
Mangan-ese**	Mangan-ese*		Magnes-ium**	Copper*	Magnes-ium***	Boron	Boron	Phos-phorus
			Copper*		Calcium ***	Phos-phorus	Phos-phorus	Iron
						Calcium	Magnes-ium	Mangan-ese
							Calcium	Copper

¹Variations were of no significance

* Variations were of questionable significance

** Variations were of moderate significance

***Variations were of definite significance

alfalfa, potassium fertilization definitely decreased the percent of all three bases, calcium, magnesium, and sodium, and likewise decreased the total milliequivalents of bases per 100 grams of plant material (Table XXVI in appendix).

Since potassium fertilization appeared to have very little effect upon most of the constituents in the plants that are important from the nutritional point of view, it is doubtful that this practice altered the nutritive value of the plants.

In an earlier part of this thesis, it has been suggested that the percent base saturation of the soil exchange complex be used as a measure of the combined base status of the soil. In order to carry this idea further, the correlation coefficients calculated for the effects of percent base saturation upon plant composition are presented in Table XIX. These values may then be used as a measure of the combined effects of the three soil cations, calcium, magnesium, and potassium, but they do not include the effects of the fourth variable in this experiment, phosphorus, upon plant composition.

The correlation coefficients in Table XIX closely resemble those reported in Table IX for the effects of the percent calcium saturation of the soil. This is due to the fact that most of the variation in percent total base saturation of the soil was accounted for by variations in the

TABLE XIX

Correlation Coefficients Between Percent Base Saturation
of the Soil and Plant Composition

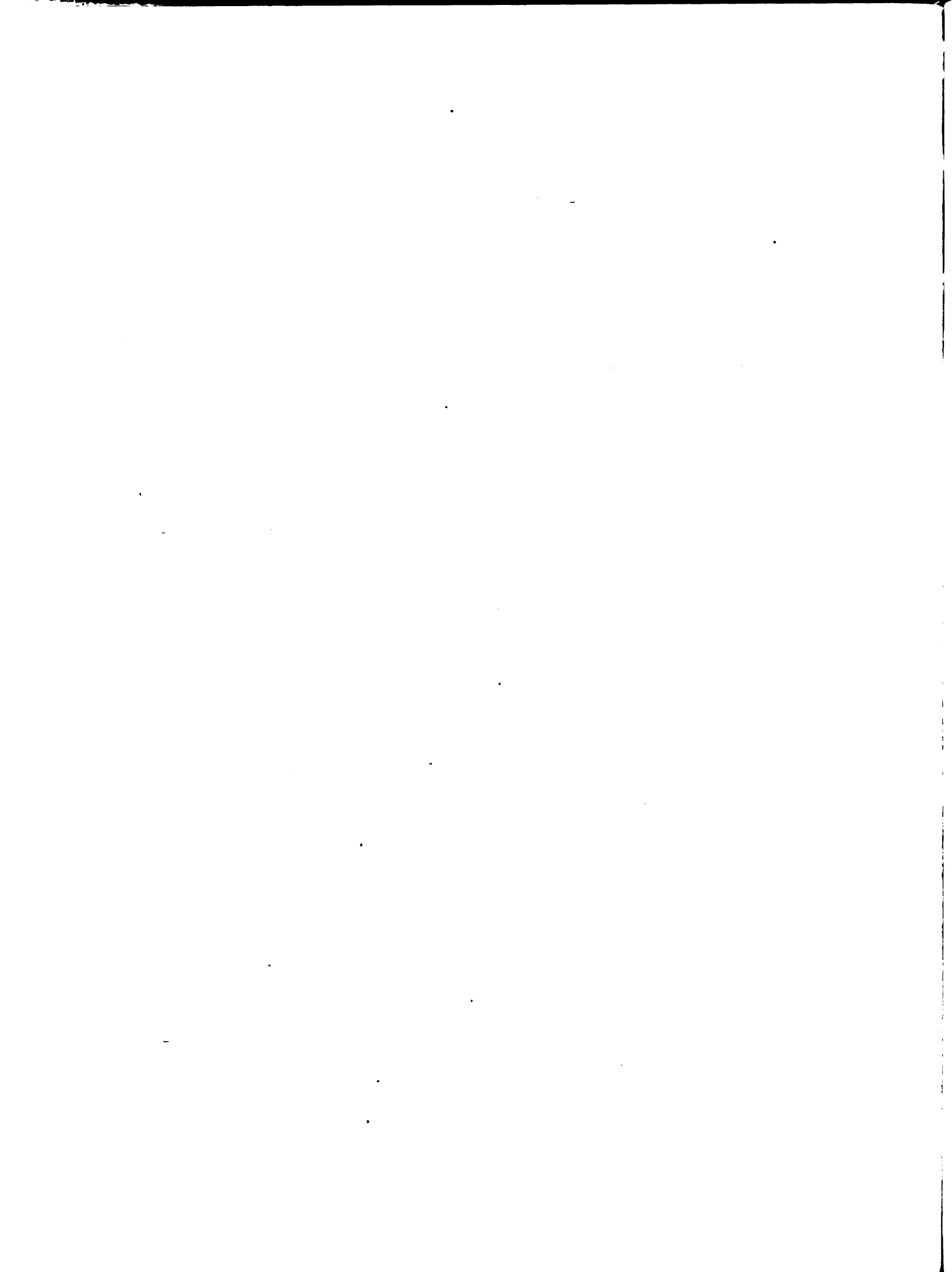
Chemical constituent	"r" Value for:		
	Soybeans	Oats	Alfalfa
Ash	0.2487*	-0.0935	-0.3126*
Crude Fiber	0.7588**	0.1171	-0.0730
Ether Extract	0.5386**	0.4946**	0.0423
Protein	0.5038**	0.0871	0.2944*
N-free Extract	-0.6421**	-0.1838	0.0424
Potassium	0.0711	-0.0026	-0.1053
Sodium	0.1817	-0.0371	-0.0099
Boron	-0.0506	-0.7580**	-0.5403**
Phosphorus	-0.4181**	-0.2163	-0.1822
Iron	0.2587*	-0.3989**	-0.1090
Magnesium	0.0525	0.3322**	0.0477
Manganese	-0.7070**	-0.2342*	-0.4571**
Calcium	0.3480**	0.4682**	0.3463**
Copper	0.0819	-0.1938	0.0747
M.e. total bases per 100 grams	0.3704**	0.3755**	0.3244**

* Significant at 5% level

**Significant at 1% level

percent calcium saturation of the soil since calcium usually represented about two-thirds of the bases present in the soil. However, in general, it may be concluded that slightly more significant variations in plant composition were caused by the combined effects of the three soil bases, calcium, magnesium, and potassium, than occurred when these bases were considered separately.

The total bases in milliequivalents per 100 grams of soybean tissue are presented in Table XXIV in the appendix. These sums were not constant for all treatments, but varied from 105 to 200 milliequivalents per 100 grams. Van Itallie (101) and others (12, 41, 63) have concluded that the sum of cations in a plant is a constant as long as the nutrients "remain in balance." They concluded that the nutrients can be considered to be out of balance for any treatment that decreased the yield. Therefore, in order to test this theory, first it was necessary to find at what point the nutrients were "out of balance." This was done by graphing the degree of base saturation against average dry weights, using the degree of base saturation in an attempt to find this point of nutrient unbalance. This graph is presented in Figure 25. It may be seen that there were no breaks in these curves, but that yield was proportional to the degree of base saturation. Therefore, no region of "nutrient unbalance" was shown.



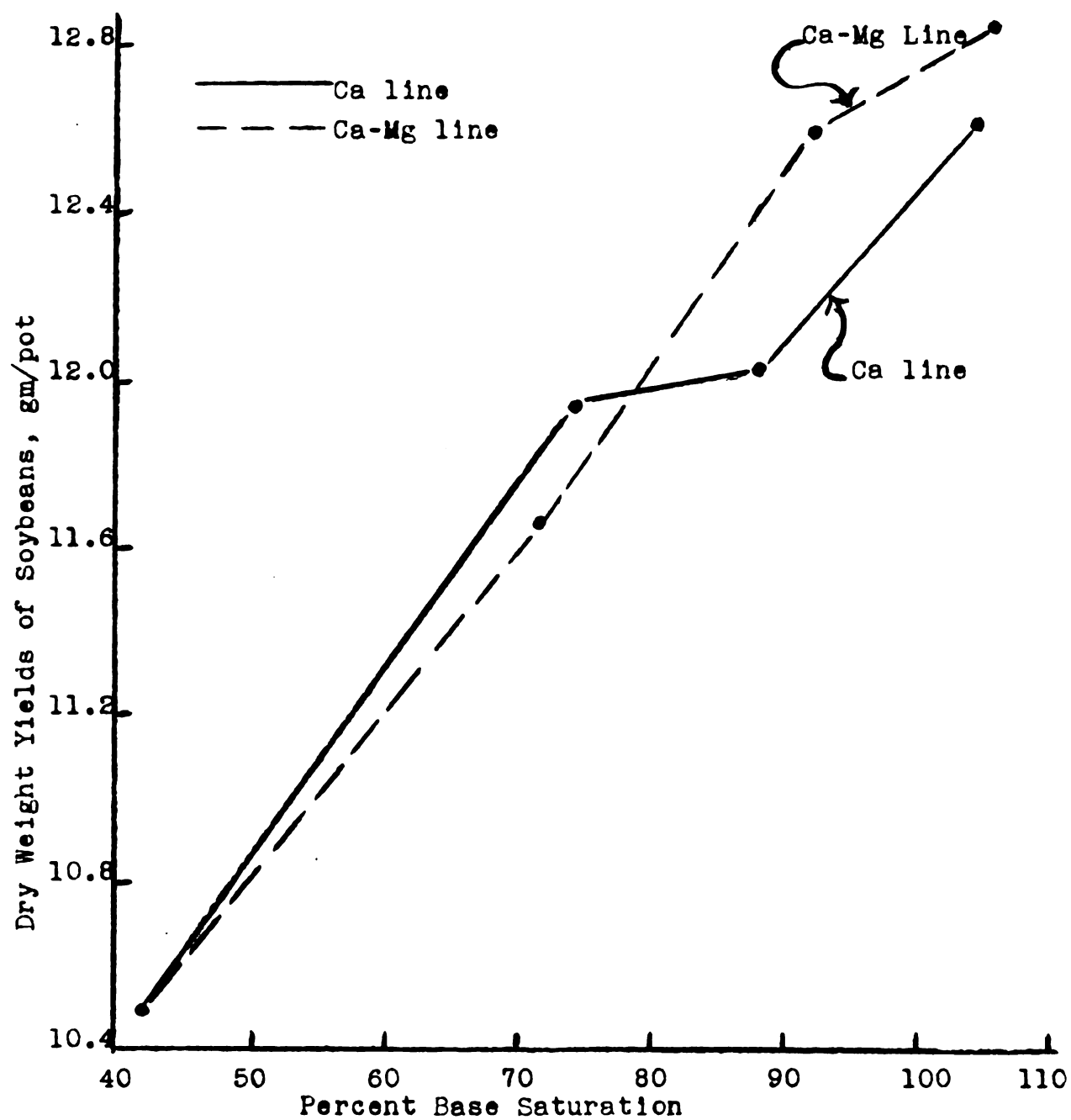


Figure 25. Effect of Percent Base Saturation upon Dry Weight Yields of Soybeans

The work of Mehlich (59) and the results of calculations made on the data presented by Chu and Turk (23) indicate that the sum of cations per unit of plant material is a function of the degree of base saturation of the soil and of the type of soil colloid. In Figure 26 the average percent base saturation of the soil for each lime treatment was calculated and plotted against the average sum of cations of the soybean plants grown at each of these pH levels. The curve in Figure 26 shows that the sum of cations was increased as the percent base saturation was increased. This was less obvious above about 75% saturation. Since this was an illitic soil (92), these results were in agreement with the conclusions of Mehlich (59) that, with the 2:1 clays, the sum of plant cations increases as the degree of base saturation of the soil is increased.

There was considerable variation in the milliequivalents of bases per unit of dry oats material for the various soil treatments (Table XXV in Appendix), the values ranging from 86 to 144 milliequivalents per 100 grams. However, these values appeared to fall into a fairly orderly arrangement when considered in respect to the percent of base saturation of the soil. Such arrangements are shown by the graphs in Figure 27. Total bases in the oats were increased to a much greater extent and much more uniformly by increasing the degree of base saturation of the soil with the mixed calcium-magnesium carbonate than by calcium carbonate alone. However,

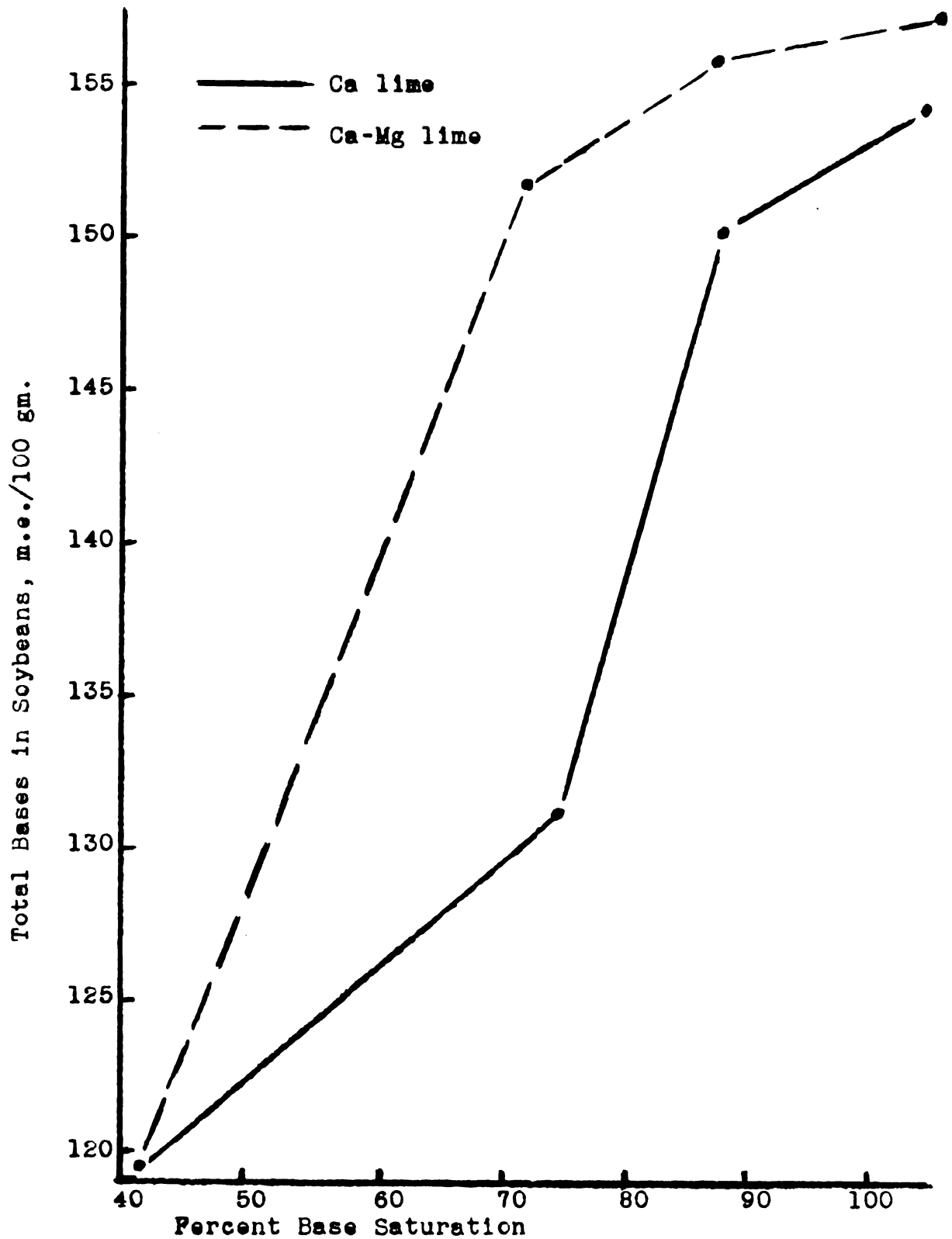


Figure 26. Effect of Percent Base Saturation of the Soil upon Total Bases in Soybeans.

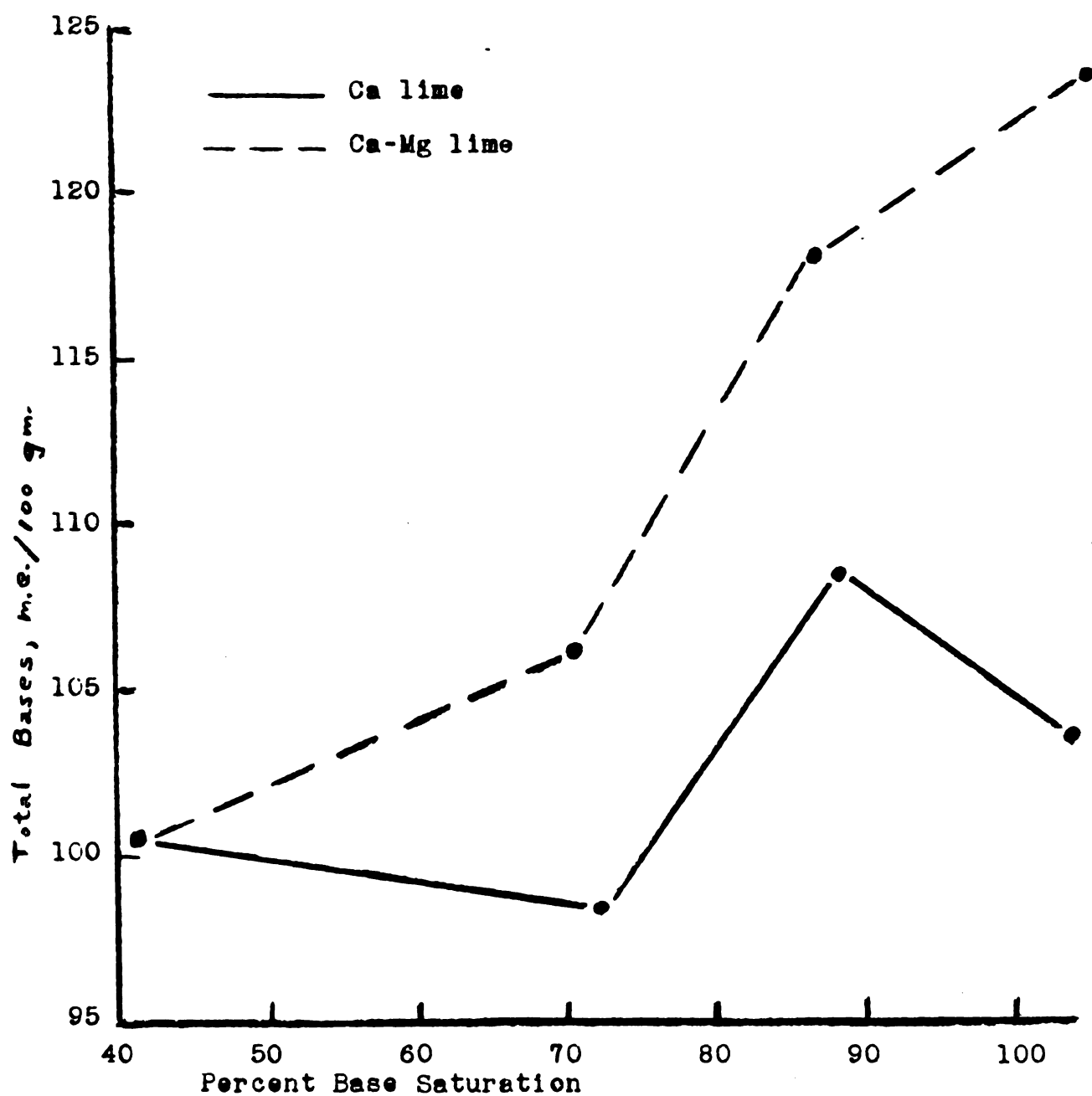


Figure 27. Effect of Percent Base Saturation of the Soil upon Total Bases in Oats.

the application of either material indicated a definite increase in total bases. Neither phosphorus nor potassium fertilization appeared to alter the total bases in the oats significantly.

The total milliequivalents of bases per 100 grams of dry alfalfa plant material are presented in Table XXVI in the appendix. As in the other two crops, the milliequivalents of total bases in the alfalfa increased consistently as the degree of base saturation of the soil was increased (Figure 28). In contrast to the results obtained with oats (Figure 27), the calcium lime gave the greater increases in total bases. Although it is not shown graphically, the total bases per 100 grams of plant material showed a continuous decrease as more potassium was applied to the soil. Phosphorus fertilization appeared to be without effect upon total bases in alfalfa.

Since the L values listed in Table XIX and the graphs in Figures 26, 27, and 28 show a close relationship between the percent base saturation of the soil and the total milliequivalents of bases in 100 grams of plant material for all three crops, these data definitely support the conclusion of Mehlich (59) that total bases in the plant is a direct function of the degree of base saturation of the soil. The slopes of the curves varied somewhat for the different kinds of plants and for the different ratios of basic cations, but all curves showed definite increases in total bases as the degree of base saturation of the soil was increased.

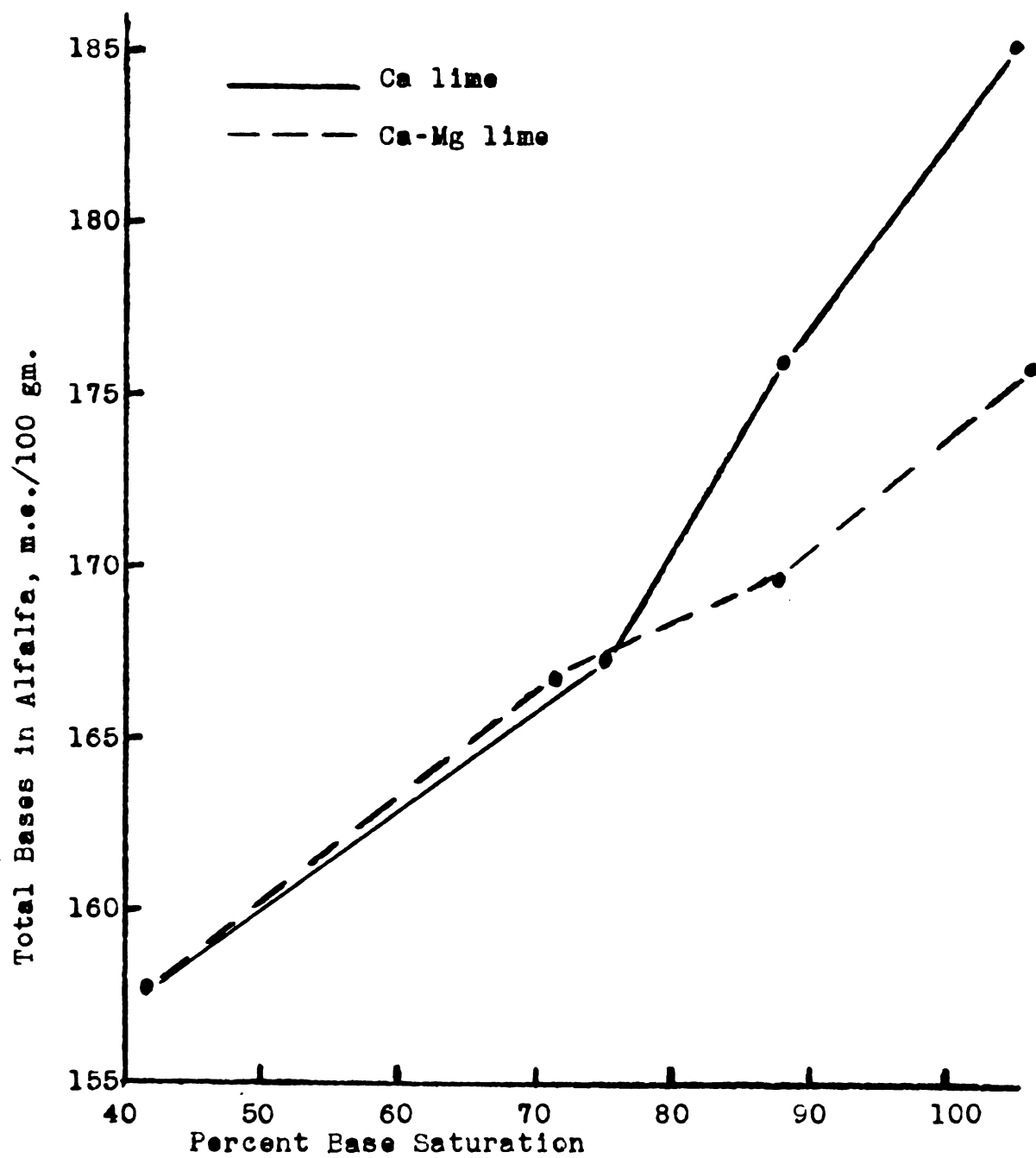


Figure 28. Effect of Percent Base Saturation of the Soil upon Total Bases in Alfalfa.

DISCUSSION

In order that the results of this study may be compared to the average composition of soybeans, oats, and alfalfa, the standard values listed in Morrison's Feeds and Feeding (65) are given in Table XX. Comparisons of those figures with the data obtained in this work will serve to demonstrate the variations in plant composition that may result from soil treatment.

The results of the chemical analyses of soybeans (Table XXI) show that the data obtained in this study differed from "average" composition in several respects. The percentages of crude fiber, sodium, and iron given in Morrison's tables were higher than those found for almost any treatment in this experiment. Also, his values for protein, N-free extract, potassium, calcium, and copper were lower than found here. It may be observed that those treatments receiving intermediate amounts of lime and fertilizers (as treatment VI-B2, for example) most closely approached the values given for soybeans in Table XX. Therefore, in considering the magnitude of the changes that occurred in plant composition with soil treatment, it might be more proper to consider the intermediate treatments as the standards and measure variations from them rather than from the controls.

The average values given in Table XX for the composition of oats hay agree very well with those found in this

TABLE XX

Standard Values for the Percent Composition of
Soybean, Oat, and Alfalfa Hays¹

Plant	Stage of Maturity	% Ash	% Crude Fiber	% Fat	% Pro- tein	% N- free extract	% K
Soybean	Seed developed	6.2	26.7	4.7	15.2	35.2	0.82 ²
Oats	Hay	6.9	28.1	2.7	8.2	42.2	0.83
Alfalfa	1/10- $\frac{1}{2}$ bloom	8.4	28.5	1.6	15.3	36.7	2.01

Plant	Stage of Maturity	% Na	% P	% Fe	% Mg	% Mn	% Ca	% Cu
Soybean	All analyses	.09	.24	.019	.44	.0105	.94	.0008
Oats	Hay	.15	.19	.049	.16	.0079	.21	--
Alfalfa	1/10- $\frac{1}{2}$ bloom	.14	.22	.025 ²	.23	.0024	1.26	.0009 ²

¹Data from Morrison's Feeds and Feeding (65).

²Hay, average of all analyses

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work (Table XXII), except for the percent protein, N-free extract, potassium, and sodium. The analyses of plants grown at low to intermediate fertility levels corresponded best to Morrison's data. The data for alfalfa did not agree so well, however. This may have been due to the fact that only the first cutting of alfalfa was analyzed in this experiment while Morrison's values included later cuttings also. Bear (11) has shown that considerable variation exists in alfalfa composition with the different cuttings.

The results of a chemical analysis of a plant may be used in many ways. However, two of the most common uses are: 1) to determine the adequacy of the nutrient supply of the soil; and, 2) to determine the effects of various treatments upon plant composition. Many assumptions and precautions are necessary in order to make a valid statement concerning the nutrient supply of the soil by considering only the results of a chemical analysis on the plant material. Once a definite procedure has been chosen and standardized in regard to such things as stage of maturity of the plants at the time of sampling, portion of plant sampled, method of analysis, and concentration of nutrients in normal tissue grown with an adequate nutrient supply, reasonably accurate predictions of plant response to soil treatments may be made for some crops at least. This conclusion is not always valid however, since it is based upon the assumption that altering the

supply of one nutrient in the soil will result in changing the concentration of only that one nutrient in the plant, but will have only minor effects upon the uptake of other nutrients. This theory is dependent upon Liebig's "Law of the Minimum" in that it assumes that the concentration of the limiting element in the plant is proportional to the soil supply of that element up to the point at which it is no longer limiting growth. It also assumes that the levels of the other nutrients in the soil determine only the length of range over which this response of the limiting element may be observed (or, in other words, the height of the growth curve). Using this as a basis, then, it may be possible to predict plant response to soil treatment from a study of the plant composition (38, 47, 98). Average percentages of the various constituents within the tissue of plants grown with adequate nutrient supplies are considered to be normal. Plants containing lower percentages of these are considered to be growing in a soil deficient in those nutrients, so a response from fertilization of the soil with those materials is predicted. Values of the percentages of various elements in a plant required for optimum growth are presented by Goodall and Gregory (38), Macy (47), and Ulrich (98), among others.

This study, however, is more concerned with the second reason listed above for making a plant analysis; that is, to determine the effect of soil treatment upon

plant composition. This problem has been approached from many directions. One of the concepts that has been employed is that of nutrient balance. Shear, Crane, and Myers (81) presented a thorough analysis of this concept. In studying the effects of nutrient supply upon plant growth and composition, two important factors must be considered; they are, the balance between the various nutrients in the growth medium, and the intensity of each nutrient. If the balance is maintained constant and the intensity altered, the growth of the plant is altered, but not the composition. If the intensity is kept constant and the balance altered, the composition, or quality, of the plant is altered. If both the factors are altered, both the quality and quantity of plant material may change. The minor elements as well as the major elements must be considered in the balance and intensity factors (40, 81, 83, 98), since there is an optimum balance and intensity for each nutrient.

Although this theory is logical, its applicability is greatly limited. In the first place, the optimum balance and intensity for each factor is unknown. Secondly, these optimums change with different conditions, so values applicable in one case are not necessarily useful under other conditions. Third, and most important, experience has taught the plant nutritionist that it is almost impossible to obtain and maintain desired balances and intensities between only

two plant nutrients. Therefore, the vastness of the problem of producing certain balances between all 15 or so elements required for plant growth may be appreciated.

For these reasons, this author, like other workers (38, 60, 98, 101, 102), does not advocate the use of nutrient ratios as measures of the nutrient supplying power of a soil. Such ratios may often be misleading because of the wide ranges over which no differences in response can be detected. For example, Mehlich and Reed (63) found that varying the Ca/K ratio of the soil from ten to one hundred, or varying the Ca/Mg ratio from four to twenty-five, had no effect on either the growth or total cations in both soybeans and oats. Similar results were obtained by Sahu (76) and Hunter (41). Only when the Ca/Mg ratio was less than one was any difference observed. In the experiment reported here the Ca/Mg ratios of the soil varied from two to twenty (Table V). The average ratios for both the four levels of phosphorus and the four levels of potassium were about the same, around four. The ratios for the mixed lime treatments all averaged slightly over two, regardless of the soil pH. Therefore, since the data presented in this paper indicated that the different treatments of phosphorus, potassium and magnesium had considerable effect upon plant growth and composition, and since these treatments did not alter the Ca/Mg ratio of the soil, it may be concluded that these ratios are not a measure of plant response to soil treatment.

Although the other cation ratios listed in Table V may have some value as measures of plant response, it must be realized that they are only one method of expressing the base status of a soil. In the opinion of this author, other methods are more practical. For example, the percent saturation of a soil by a given base is as valid a measure since both the percent saturation and the cation ratios are calculated from basically the same data. Also the percent base saturation is more readily interpreted since it expresses the concentration of the base in relation to the whole soil, not just in relation to another base. In addition, percent saturation is a measure of both the balance and intensity factors while a cation ratio measures only balance, but not intensity. For these reasons, and since the literature also shows relationships between base saturation and plant response not detected when cation ratios are used, in this thesis the percent base saturation rather than cation ratios has been relied upon as a measure of soil treatment.

Much work has been done relating the percent base saturation of the soil to plant growth and composition, particularly by Mahlich and co-workers. Starting from the fact that the percent base saturation of the soil is a factor in determining the activity of a base (10, 44, 48, 49, 50, 60), it has been found that the availability of a cation to a plant is dependent upon the activity of that cation on the soil colloid. Therefore, since the uptake of

a cation is conditioned by its availability, a relationship should exist between the percent of a given cation in the plant and the percent saturation of the soil by that cation. Many such relationships have been found (2, 7, 44, 59, 60, 61, 62, 63, 74, 100, 102, 106).

The data presented in this thesis showed that the percent calcium plus magnesium and percent potassium saturation of the soil was almost directly proportional to soil pH and pounds per acre of available potassium respectively (Figures 4 and 5). Therefore, the curves relating plant composition to soil pH or potassium (Figures 16, 17, 18, 22, 23, and 24) also expressed the relationship between plant composition and the percent base saturation of the soil by these bases. Therefore, the discussions pertaining to these graphs are also applicable to a discussion of the effects of base saturation on plant composition.

The results of this experiment are then in agreement with those of Allaway (2) who found that calcium uptake by soybeans increased as the degree of calcium saturation of an illitic soil was increased. Similar data have been reported by Mehlich and Coleman (60) and others. The work reported here also definitely supports the conclusion of Mehlich (59) that the sum of total bases in plants grown on an illitic soil is a function of the degree of base saturation of the soil. The papers of Welch and Nelson (106), Allaway (2), Mehlich and Coleman (60), Mehlich and Colwell (61, 62), and

and Mehlich (59) among others also have shown some of the effects that the different types of soil colloids have upon plant (quite frequently soybean) composition and growth. In addition, these papers have shown that the type of colloid, as well as the percent base saturation, is important in determining the availability and uptake of cations. These differences probably arise from the differences in the bonding energies of the different types of colloids. Thus, the availability of a cation would be determined not only by its quantity in the soil, but also by its relative attraction to the soil colloid and plant root. Its relative attraction would be determined by the valence and size of the cation, strength of the electrostatic attraction of both the colloid and root (that is, type of colloid and kind of plant), kind and concentration of complementary ions, plus many more factors unknown as yet.

The data in this study have demonstrated some definite differences in the composition of the different types of plants. One of the most noticeable of these differences was the higher percentage of divalent cations and lower monovalent cation content of the legumes as compared to the oats. Drake, et al (29) and Elgabaly and Wilklander (35) attempted to explain this phenomenon upon the basis of the differences in the cation exchange capacity of the roots of the different kinds of plants. According to this theory, the distribution of cations is determined by a Donnan equilibrium, the cell

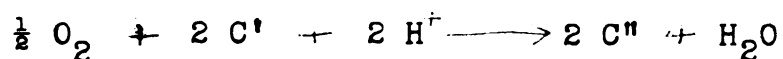
wall being the semi-permeable membrane. Thus, the divalent ions, because of their greater charge, would tend to accumulate on the material having the highest cation exchange capacity. For a given type of soil colloid, then, the legumes would accumulate divalent ions to a greater extent than the grasses since the cation exchange capacity of the legume roots is higher than that of the grass roots (29). However, recent work by McLean and Adams (58) indicates that this picture is over-simplified. They found that calcium was held almost twice as strongly as potassium by both oats and alfalfa roots, and that the strength of this bond was not related to the cation exchange capacity of the roots.

The basic mechanisms by which soil nutrients enter into the plant cells are unknown. However, there is growing evidence that the concept presented by Lundegradh (46, 69, 102) has considerable merit in explaining these mechanisms. This theory was developed upon the assumption that cations and anions enter into a plant independently of each other. According to the theory, soil cations are merely adsorbed by exchange reactions with cations, mainly hydrogen ions produced by dehydrogenase activity in plant metabolism (102), in the plant root. An "exchange track" is visualized extending from the root hair into the vacuole of the cell, and the adsorbed cations move into the cell along this track in a wave motion. It must be possible for this process to occur independently of aerobic respiration of the cell because it

has been shown that cations may be adsorbed in an atmosphere of nitrogen gas. Also, it has been demonstrated that cation uptake occurs with dead roots (42, 46, 102), and that the uptake of cations is only slightly increased by increasing the temperature of the roots from 0° C to 25° C (43). Since these facts indicate that exothermic chemical reactions in the cell are not necessary for this process, cation uptake would merely be a Donnan situation.

Lundegradh's theory views the anions as entering the plant through the action of the cytochrome-cytochrome oxidase system. The Fe^{+2} cytochrome, because it is in a reduced condition, will migrate toward a region of high oxidization potential, or toward the surface of the cell. Meanwhile, the oxidized Fe^{+3} cytochrome will move to the interior of the cell where a lower oxidization potential exists, setting up a cyclic movement in the cytochrome system. As the oxidized cytochrome moves inward, three milliequivalents of anions are carried in with the Fe^{+3} . The reduced cytochrome carries two equivalents of anions and one electron outward, so the net result would be the accumulation of one equivalent of anion for each electron removed from the system. Since the initial source of these electrons is from the external oxygen molecule, each mole of oxygen used in the respiration of the plant roots should result in the accumulation of four equivalents of anions in the plant. Evidence has been obtained supporting this conclusion (69, 102).

Overstreet and Jacobson (69) related Lundegradh's theory to other theories of ion uptake (68, 75) by showing that cation and anion uptake are not strictly independent. Since each cation taken into the root releases one hydrogen ion and each anion taken into the root requires one-fourth mole of oxygen, and since total cations in the plant must equal total anions to maintain chemical neutrality, the net relationship between the cation and anion reactions may be expressed by the equation:



where $C' = Fe^{+2}$ cytochrome, and $C'' = Fe^{+3}$ cytochrome.

Although total equivalents of cations in the plant must equal total equivalents of anions, the uptake of the two kinds of ions need not necessarily be equal. An excess of mineral cations, for instance, may be neutralized in the plant by the production of organic acids (41, 43, 95, 96). In an extensive study of this phenomenon, Jacobson and Ordin (42) found that most of this increase in organic acids was accounted for by an increase in malic acid. They showed that the addition of potassium bromide to the substrate promoted the uptake of both potassium ions and bromide ions in almost equal quantities, so had very little effect upon the organic acid content of the roots. This occurred presumably because the activities of these two ions were about the same. However, with potassium bicarbonate, cation uptake was

greater than anion uptake, so the organic acid content (especially malic acid) increased to the extent that it neutralized the excess anions. On the other hand, the addition of calcium bromide caused a greater uptake of anions, so organic acids decreased through oxidization, resulting in a respiration quotient of over one. Ulrich (95, 96) had also noticed this increased respiration quotient under similar conditions. The source of the malic acid is unknown, but it is presumably from alterations in the reaction rates, caused by changing conditions controlling enzyme activity, of the steps in glycolysis and the Kreb's cycle.

Applying this concept to this experiment, the addition of large amounts of potassium chloride to the soil should not seriously have altered the organic acid content of the plant since both potassium ions and chloride ions have about the same activities. However, large applications of potassium chloride in combination with phosphate might result in an increase in organic acids. If this happened, this increase would be accounted for mainly in the N-free extract content of those plants grown at high levels of soil potassium and phosphorus (C3 treatments). The data on the chemical analyses of the three crops studied here do not support this conclusion. However, recalling the fact that N-free extract was calculated by difference and that the organic acids constitute only a small part of the N-free extract fraction, these data do not necessarily disprove this idea.

One of the objectives of this experiment was to determine the effects of liming and fertilization upon the nutritive value of forage plants. The degree to which such a study could be made from the previous data reported in this paper is valid only to the extent that the composition of a plant is a valid measure of its nutritive value. However, it is well known that such determinations do not always give reliable results when compared to feeding trials or other methods of biological assay (15, 52, 83). An increase in protein content, for instance, does not necessarily indicate that the plant has greater nutritive value (64), although this is generally true if fed in a balanced ration (70).

Probably the best individual measures of the nutritive value of a plant are the percent protein, phosphorus, and calcium, in that order. Also, the ash, magnesium, N-free extract, and iron contents may have some value in this respect. On the other hand, lower nutritive value is usually associated with an increase in crude fiber content. However, the relative importance of variations in each of these constituents is dependent upon other conditions and chemical changes in plant composition. For example, it has been shown previously in this thesis that phosphorus fertilization resulted in increased phosphorus and calcium content but decreased protein content in oats. From these data

alone, it is impossible to state without qualification that phosphorus either increased or decreased the nutritive value of the oats. If the oats hay were supplemented in the cattle ration with such material as bone-meal, feeding trials would probably indicate that phosphorus fertilization resulted in producing oats plants of lower nutritive value. On the other hand, if the hay were supplemented with a protein supplement, the feeding trials would probably indicate positive effects for phosphorus fertilization. Thus, it may be seen that it is impossible to make relative comparisons as to the effects of fertilization upon the nutritive value of plants without defining the conditions under which the comparison is made. Since these conditions are not constant, it is quite difficult to make unqualified statements with respect to the nutritive value of the plants grown under different fertility treatments. Before such generalizations can be made, the relative importance of increased phosphorus content at the expense of decreased protein content, for example, must first be ascertained.

CONCLUSIONS AND SUMMARY

A study was made concerning the effects of liming and fertilization upon plant growth and composition in an attempt to evaluate the influence of these soil treatments upon altering the nutritive value of forages. Generally, the percent protein, phosphorus, calcium, crude fiber, iron, and ash are most often used as measures of the nutritive value of a plant. In making this summary of the results of this work, variations in the percentages of these six constituents were considered primarily in determining the effects of soil treatment upon the nutritive value of the plants. In general, the importance given to variations in the percent of these constituents were in the same order as listed above; that is, protein was considered as being most important, and iron and ash as least important.

The variations in dry weight and plant composition of the soybeans, oats, and alfalfa grown in the greenhouse with varying levels and kinds of lime and levels of monocalcium phosphate and potassium chloride treatments are summarized as follows:

1. Under the conditions of this experiment, the type of lime used had very little influence upon plant growth or composition. The only differences of significance were that the addition of magnesium carbonate to the soil generally resulted in a plant higher in percent magnesium and lower in percent calcium.

2. The effects of changing soil pH upon plant growth varied with the different plants. With soybeans, dry weight yield was proportional to soil pH. With oats and alfalfa, only a slight response to liming was noted at a soil pH above 5.8.

3. With the legumes, plant growth failed to respond significantly to phosphorus fertilization when available phosphorus was above 30 pounds per acre. However, for the oats, a definite positive response was observed.

4. Potassium fertilization appeared to have a quite varied effect upon plant growth. Increasing available potassium to 100 pounds per acre or above resulted in decreased growth for soybeans; initially an increase followed by a decrease in the growth of oats; and no significant change in alfalfa growth.

5. In most cases, phosphorus fertilization in combination with the calcium-magnesium liming mixture increased dry weight production significantly, indicating that increasing the supply of soil magnesium may increase the effectiveness of phosphate fertilization upon plant growth. However, there was little evidence to indicate that increasing the magnesium supply of the soil increased the percent phosphorus in the plant.

6. In general, changes in plant composition resulting from liming or phosphating varied considerably for the

different species of plants, and even more so for the different families of plants. Potassium fertilization appeared to have much the same effect on plant composition in all three species.

7. The addition of lime to the soils increased the percentage of crude fiber, ether extract, protein, iron, and calcium, and decreased the percent N-free extract, boron, phosphorus, and manganese in the soybeans.

8. Adding lime to the soil increased only the percent calcium in the oats, but decreased the percent ash and all the minor elements. Thus, it appeared that liming may have slightly decreased the nutritive value of the oats plants.

9. When lime was applied to the soil in which alfalfa was grown, it caused an increase in the percent ash, protein, and calcium, but a decrease in boron, iron, and manganese contents of the hay. This shows that liming undoubtedly improved the nutritive value of the alfalfa.

10. Increasing the supply of soil phosphorus resulted in increased percentages of ash, ether extract, protein, sodium, and phosphorus in the soybeans. Since only the N-free extract and boron contents were definitely decreased, this treatment resulted in plants of higher nutritive values.

11. Phosphorus fertilization of the oats increased the N-free extract, phosphorus, and calcium contents while

decreasing the iron and protein contents, so probably had very little net effect upon altering the nutritive value of the plants.

12. The effects of adding phosphates to the soil upon alfalfa composition included an increase in ash, phosphorus, and iron contents, but a decrease in the percent sodium and copper. Therefore, this practice increased the nutritive value of the alfalfa.

13. Potassium fertilization produced soybeans containing a higher percentage of ash, potassium, and manganese. Since only the percent magnesium was reduced, this soil treatment had very little effect upon the nutritive value of this crop.

14. An increase in available soil potassium increased ash and potassium, but decreased the ether extract, sodium, boron, and iron contents of the oats. Thus potassium fertilization failed to alter appreciably the feeding value of the oats.

15. Increasing soil potassium increased only the percent potassium in the alfalfa while decreasing the percent of the other three bases, sodium, calcium, and magnesium. Therefore, its effect upon the nutritive value of the alfalfa was very slight.

16. In general, phosphorus fertilization had the greatest tendency of all the soil amendments to produce

plants of higher nutritive value, especially with the legumes. The effects of liming appeared to be quite dependent upon the nature of the plant, while potassium fertilization had the least effect.

17. The percent base saturation of the soil exchange complex was a better measure of soil fertility status than were cation ratios because the former measured both the balance and intensity of nutrients while the latter measured only the balance.

18. The results of the chemical analyses of all three crops supported the theory that the total milliequivalents of bases per 100 grams of dry plant material is a direct function of the degree of base saturation of an illitic soil.

19. The fertility status of the soil is only one of many variables determining plant composition. Also, the value of plant composition as a criterion of the nutritive value of the plant is dependent upon many external variables. Therefore, feeding trials or other methods of biological assay would be of great value in confirming these conclusions in regard to the effects of soil treatments upon the nutritive value of plants.

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APPENDIX

TABLE XXI.

Chemical Composition of Soybeans*

Treat- ment	Ash	Crude Fiber	Ether Extract	Protein	N-free Extract	Na	K
I-0	4.65	20.07	2.86	16.13	56.29	.027	1.00
II-0	5.27	19.72	3.41	14.81	56.79	.030	0.758
III-0	6.08	20.38	3.28	16.00	54.26	.033	0.799
IV-0	5.71	19.91	3.96	17.25	53.17	.031	0.814
V-0	5.79	19.85	4.28	16.38	53.70	.031	0.820
VI-0	5.58	20.76	4.54	16.75	52.37	.033	0.740
VII-0	5.92	20.72	3.81	16.56	52.99	.045	0.720
I-A1	4.99	19.28	2.33	16.13	57.27	.031	1.110
II-A1	5.36	20.95	4.12	16.94	52.63	.040	1.21
III-A1	5.65	21.27	3.97	17.38	51.73	.058	0.968
IV-A1	5.65	21.75	4.62	18.94	49.94	.040	1.07
V-A1	5.52	21.80	4.53	18.19	49.57	.039	1.01
VI-A1	5.25	20.33	4.29	16.63	53.50	.049	0.953
VII-A1	5.61	20.94	3.96	17.75	51.74	.038	0.909
I-A2	5.41	18.28	1.86	15.31	59.14	.044	1.18
II-A2	5.60	20.94	3.53	16.81	53.12	.051	1.14
III-A2	5.86	22.07	3.79	18.56	49.72	.054	1.15
IV-A2	5.63	21.21	4.82	17.69	50.65	.046	1.15
V-A2	5.29	20.95	4.06	16.81	52.89	.038	1.19
VI-A2	5.82	20.90	4.34	18.19	50.75	.046	1.10
VII-A2	5.67	20.79	4.52	18.31	50.71	.034	1.12
I-A3	6.57	15.21	1.35	16.56	60.31	.048	1.34
II-A3	6.58	21.70	4.82	19.69	47.21	.044	1.37
III-A3	6.09	22.55	3.18	17.38	50.80	.041	1.40

*Values expressed as percent

Table XXI. (continued)

Treat- ment	B	P	Fe	Mg	Mn	Ca	Cu
I-0	.0043	.270	.0142	.462	.0810	1.30	.0017
II-0	.0032	.082	.0062	.327	.0125	1.17	.0010
III-0	.0029	.052	.0085	.322	.0092	1.25	.0015
IV-0	.0040	.170	.0121	.456	.0117	2.33	.0015
V-0	.0042	.167	.0163	.572	.0138	1.63	.0020
VI-0	.0039	.203	.0096	.710	.0110	2.06	.0014
VII-0	.0035	.214	.0128	.803	.0098	2.12	.0012
I-A1	.0027	.343	.0088	.329	.132	0.92	.0009
II-A1	.0026	.277	.0067	.293	.0162	1.29	.0009
III-A1	.0030	.224	.0090	.311	.0177	2.04	.0009
IV-A1	.0029	.271	.0127	.347	.0112	1.85	.0016
V-A1	.0032	.218	.0090	.520	.0180	1.50	.0011
VI-A1	.0026	.306	.0121	.585	.0125	1.66	.0010
VII-A1	.0026	.250	.0298	.670	.0115	1.62	.0011
I-A2	.0029	.341	.0088	.278	.163	0.79	.0012
II-A2	.0029	.171	.0074	.278	.0167	1.22	.0013
III-A2	.0026	.210	.0103	.310	.0148	1.53	.0010
IV-A2	.0031	.309	.0183	.306	.0108	1.60	.0020
V-A2	.0032	.238	.0088	.470	.0177	1.56	.0010
VI-A2	.0032	.344	.0122	.550	.0145	1.64	.0013
VII-A2	.0028	.322	.0114	.561	.0120	1.81	.0011
I-A3	.0030	.353	.0063	.306	.204	0.76	.0011
II-A3	.0026	.220	.0095	.282	.0182	1.24	.0013
III-A3	.0036	.258	.0124	.316	.0200	2.07	.0012

Table XXI. (continued)

Treat- ment	Ash	Crude Fiber	Ether Extract	Protein	N-free Extract	Na	K
IV-A3	5.91	21.80	4.53	18.19	49.57	.040	1.24
V-A3	6.07	21.24	4.98	18.81	48.90	.044	1.30
VI-A3	6.12	21.80	3.60	19.06	49.42	.049	1.25
VII-A3	6.32	20.61	4.25	18.63	50.73	.029	1.20
I-B1	5.98	18.47	3.45	17.19	54.91	.033	1.11
II-B1	6.62	21.07	5.21	20.13	46.97	.039	0.994
III-B1	7.11	22.02	5.34	20.31	45.22	.039	1.01
IV-B1	6.42	21.41	6.06	21.94	44.17	.043	1.18
V-B1	5.86	20.85	5.28	19.25	48.76	.042	1.11
VI-B1	6.04	19.68	4.23	19.50	50.55	.044	0.964
VII-B1	6.32	20.31	4.62	20.38	48.37	.046	0.896
I-B2	6.32	19.09	2.78	16.94	54.87	.034	1.31
II-B2	6.46	20.83	6.01	20.69	46.01	.040	1.23
III-B2	6.51	20.51	5.16	19.81	48.01	.044	1.21
IV-B2	6.65	21.11	5.74	22.75	43.75	.046	1.29
V-B2	6.04	20.25	4.54	17.94	51.23	.042	1.16
VI-B2	6.01	22.01	4.06	18.95	48.98	.044	1.13
VII-B2	6.10	20.40	4.45	20.50	48.55	.050	1.20
I-B3	7.26	17.60	1.64	16.44	57.06	.038	1.39
II-B3	6.76	21.96	5.07	18.50	47.71	.039	1.29
III-B3	6.65	21.72	4.69	20.00	46.94	.042	1.50
IV-B3	6.87	21.23	6.25	22.56	43.09	.043	1.42
V-B3	6.75	20.37	5.37	20.25	47.26	.045	1.38
VI-B3	6.66	20.95	4.29	20.38	47.72	.052	1.31
VII-B3	6.80	20.13	5.63	23.56	43.88	.045	1.33

Table XXI (continued)

Treat- ment	B	P	Fe	Mg	Mn	Ca	Cu
IV-A3	.0033	.412	.0162	.308	.0118	1.83	.0021
V-A3	.0029	.210	.0072	.440	.0188	1.39	.0012
VI-A3	.0029	.323	.0111	.536	.0142	1.62	.0012
VII-A3	.0025	.249	.0097	.575	.0128	1.86	.0012
I-B1	.0042	1.026	.0137	.408	.187	1.39	.0019
II-B1	.0020	.289	.0092	.401	.0230	1.40	.0026
III-B1	.0023	.360	.0111	.417	.0185	1.83	.0029
IV-B1	.0022	.321	.0105	.395	.0135	2.07	.0039
V-B1	.0029	.308	.0098	.501	.0185	1.21	.0027
VI-B1	.0030	.268	.0147	.574	.0135	1.30	.0035
VII-B1	.0026	.214	.0109	.675	.0130	1.43	.0032
I-B2	.0048	.934	.0137	.403	.233	1.27	.0019
II-B2	.0040	.375	.0122	.372	.0241	1.83	.0021
III-B2	.0032	.346	.0134	.326	.0180	1.91	.0022
IV-B2	.0025	.361	.0113	.479	.0140	1.44	.0015
V-B2	.0027	.179	.0076	.503	.0197	1.27	.0018
VI-B2	.0025	.200	.0091	.558	.0142	1.40	.0017
VII-B2	.0028	.257	.0113	.479	.0140	1.44	.0015
I-B3	.0046	.958	.0097	.413	.290	1.43	.0024
II-B3	.0020	.241	.0109	.293	.0218	1.33	.0024
III-B3	.0032	.446	.0129	.293	.0190	1.82	.0017
IV-B3	.0027	.296	.0075	.280	.0130	1.78	.0019
V-B3	.0027	.285	.0072	.474	.0212	1.47	.0014
VI-B3	.0023	.274	.0072	.455	.0142	1.16	.0035
VII-B3	.0023	.340	.0098	.601	.0142	1.40	.0016

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Table XXI. (continued)

Treat- ment	Ash	Crude Fiber	Ether Extract	Protein	N-free Extract	Na	K
I-C1	6.23	19.72	4.92	24.13	45.00	.047	1.33
II-C1	6.85	20.19	5.17	28.88	48.91	.053	0.903
III-C1	7.10	21.75	5.24	21.13	44.78	.050	0.810
IV-C1	7.63	21.92	4.88	23.63	41.94	.053	0.854
V-C1	8.65	21.35	3.95	21.88	44.17	.055	1.15
VI-C1	7.01	21.72	4.58	21.25	45.44	.045	0.888
VII-C1	6.99	21.24	5.96	22.13	43.68	.052	0.836
I-C2	6.65	19.66	2.66	17.06	53.97	.048	1.27
II-C2	7.05	20.97	5.19	19.63	46.16	.052	1.21
III-C2	7.10	22.05	5.00	21.44	44.41	.054	1.25
IV-C2	7.62	22.18	5.02	23.00	42.18	.056	1.24
V-C2	6.66	19.70	4.79	18.75	50.10	.054	1.12
VI-C2	6.51	22.14	4.45	20.75	46.15	.050	1.11
VII-C2	6.88	21.25	5.11	22.31	44.45	.052	1.16
I-C3	6.99	19.65	2.11	15.75	55.50	.048	1.41
II-C3	7.22	22.49	4.36	20.81	45.12	.056	1.37
III-C3	7.73	23.01	4.32	23.88	41.06	.052	1.45
IV-C3	7.56	20.83	5.67	23.38	42.56	.059	1.38
V-C3	7.13	20.84	4.32	20.19	47.52	.054	1.32
VI-C3	7.12	21.41	4.76	22.50	44.21	.053	1.32
VII-C3	7.34	20.43	5.31	22.31	44.61	.051	1.38

Treat- ment	B	P	Fe	Mg	Mn	Ca	Cu
I-C1	.0030	.650	.0068	.420	.112	1.08	.0018
II-C1	.0023	.330	.0073	.360	.0190	1.58	.0020
III-C1	.0024	.371	.0111	.396	.0167	1.86	.0018
IV-C1	.0020	.199	.0098	.353	.0128	1.79	.0012
V-C1	.0036	.645	.0104	.757	.0265	1.90	.0021
VI-C1	.0027	.434	.0088	.730	.0150	1.50	.0018
VII-C1	.0019	.299	.0069	.685	.0101	1.21	.0020
I-C2	.0037	.648	.0064	.358	.177	1.26	.0016
II-C2	.0025	.366	.0112	.324	.0225	1.47	.0020
III-C2	.0024	.285	.0098	.324	.0172	1.68	.0020
IV-C2	.0017	.258	.0113	.286	.0122	1.53	.0014
V-C2	.0028	.394	.0086	.626	.0202	1.39	.0020
VI-C2	.0029	.503	.0136	.514	.0133	1.82	.0016
VII-C2	.0018	.202	.0081	.509	.0113	1.15	.0016
I-C3	.0030	.348	.0082	.330	.177	1.26	.0016
II-C3	.0027	.247	.0092	.299	.0200	1.81	.0012
III-C3	.0029	.681	.0136	.303	.0148	1.97	.0017
IV-C3	.0017	.347	.0149	.357	.0118	1.55	.0014
V-C3	.0024	.398	.0089	.587	.0185	1.31	.0020
VI-C3	.0020	.317	.0088	.568	.0142	1.29	.0021
VII-C3	.0020	.300	.0112	.464	.0125	1.27	.0011

TABLE XXII
Chemical Composition of Oats*

Treat- ment	Ash	Crude Fiber	Ether Extract	Protein	N-free Extract	K	Na
I-0	10.22	25.64	4.01	15.69	44.44	1.92	.956
II-0	6.55	28.68	3.27	11.38	50.12	0.99	1.19
III-0	7.85	27.27	3.33	13.75	47.80	1.36	1.12
IV-0	7.69	28.69	3.25	13.75	46.62	1.40	1.03
V-0	7.34	30.39	2.69	11.56	48.02	1.20	1.21
VI-0	7.34	28.71	2.90	12.13	48.92	1.21	1.07
VII-0	6.72	28.88	3.10	13.69	47.61	1.15	1.09
I-A1	6.55	28.80	1.97	9.81	52.87	1.52	.742
II-A1	6.50	30.22	2.92	10.44	49.92	1.37	.984
III-A1	5.84	28.37	3.42	10.69	51.68	1.15	.742
IV-A1	5.93	29.93	3.06	11.25	49.83	1.08	.818
V-A1	6.43	29.12	2.93	10.19	51.33	1.37	.744
VI-A1	6.54	28.52	2.93	10.44	51.57	1.33	.800
VII-A1	6.23	28.95	3.07	10.19	51.56	1.28	.940
I-A2	6.83	29.02	1.73	9.25-	53.17	2.05	.364
II-A2	6.71	29.00	2.74	9.81	51.74	2.12	.376
III-A2	7.07	28.39	2.33	11.63	50.58	2.39	.286
IV-A2	7.03	29.61	2.24	9.50	51.62	2.20	.446
V-A2	6.90	28.98	2.03	9.06	53.03	2.25	.316
VI-A2	6.80	29.85	2.26	10.31	50.78	2.09	.492
VII-A2	6.54	28.55	3.45	10.25	51.20	2.00	.304
I-A3	7.90	29.92	1.58	11.44	49.16	2.86	.098
II-A3	7.41	28.69	2.79	10.25	50.90	2.75	.070
III-A3	7.51	30.38	3.12	9.69	49.30	2.79	.062

*Values expressed as percent

Table XXII. (continued)

Treat- ment	B	P	Fe	Mg	Mn	Ca	Cu
I-0	.0046	.359	.2550	.215	.0370	0.43	.0100
II-0	.0024	.278	.0111	.168	.0065	0.21	.0022
III-0	.0021	.219	.0118	.220	.0050	0.49	.0022
IV-0	.0022	.207	.0192	.162	.0075	0.38	.0017
V-0	.0022	.191	.0053	.214	.0040	0.12	.0016
VI-0	.0017	.181	.0250	.265	.0051	0.27	.0013
VII-0	.0020	.239	.0086	.400	.0059	0.57	.0016
I-A1	.0021	.340	.0178	.180	.0440	0.14	.0013
II-A1	.0026	.303	.0162	.173	.0092	0.43	.0022
III-A1	.0019	.219	.0072	.155	.0073	0.37	.0022
IV-A1	.0019	.213	.0058	.132	.0062	0.32	.0019
V-A1	.0012	.197	.0038	.187	.0059	0.10	.0015
VI-A1	.0024	.305	.0107	.314	.0067	0.36	.0019
VII-A1	.0017	.274	.0047	.336	.0073	0.46	.0015
I-A2	.0021	.338	.0168	.148	.0385	0.18	.0015
II-A2	.0017	.228	.0061	.125	.0089	0.19	.0018
III-A2	.0022	.251	.0064	.175	.0084	0.40	.0017
IV-A2	.0019	.247	.0072	.146	.0069	0.39	.0019
V-A2	.0011	.174	.0046	.228	.0089	0.13	.0015
VI-A2	.0019	.278	.0072	.360	.0079	0.36	.0019
VII-A2	.0018	.340	.0072	.360	.0090	0.57	.0019
I-A3	.0028	.417	.0181	.158	.0610	0.18	.0015
II-A3	.0013	.213	.0053	.121	.0147	0.14	.0028
III-A3	.0018	.254	.0056	.165	.0099	0.36	.0013

Table XXII. (continued).

Treat- ment	Ash	Crude Fiber	Ether Extract	Protein	N-free Extract	K	Na
IV-A3	7.36	29.53	3.60	11.31	48.20	2.78	.110
V-A3	7.37	30.34	2.54	9.81	49.85	2.77	.193
VI-A3	7.51	29.76	2.99	10.25	49.49	2.62	.112
VII-A3	7.30	30.31	2.60	12.44	47.35	2.57	.126
I-B1	6.54	30.99	1.68	9.06	51.73	1.31	.822
II-B1	6.42	29.42	3.39	9.31	51.46	1.16	.882
III-B1	6.56	29.37	2.36	10.38	51.33	1.26	.824
IV-B1	6.23	28.96	3.07	10.94	50.80	1.19	.916
V-B1	6.21	28.08	3.69	9.50	52.52	1.21	.840
VI-B1	6.49	28.62	3.43	9.31	52.15	1.18	.930
VII-B1	6.32	29.36	3.46	10.38	50.48	1.07	.828
I-B2	7.69	28.69	1.53	10.25	51.84	2.62	.290
II-B2	6.87	30.66	2.61	9.63	50.23	2.21	.420
III-B2	6.78	30.17	2.87	9.81	50.37	2.34	.392
IV-B2	6.83	29.70	2.76	9.94	50.77	2.30	.400
V-B2	6.83	28.93	2.70	9.00	52.54	2.12	.297
VI-B2	7.02	29.53	3.26	9.94	50.25	2.12	.320
VII-B2	6.49	30.22	3.07	9.31	50.91	1.89	.387
I-B3	7.42	28.58	1.55	10.50	51.95	2.52	.236
II-B3	6.81	27.50	2.49	9.19	54.01	2.58	.150
III-B3	7.08	28.71	2.74	9.38	52.09	2.61	.164
IV-B3	6.84	27.57	2.80	10.56	52.23	2.52	.160
V-B3	6.97	29.79	2.23	9.06	51.95	2.48	.178
VI-B3	7.11	28.52	2.55	10.13	51.69	2.43	.200
VII-B3	7.65	27.77	2.71	11.38	50.49	2.50	.208

Table XXII. (continued)

Treat- ment	B	P	Fe	Mg	Mn	Ca	Cu
IV-A3	.0017	.222	.0068	.157	.0098	0.47	.0019
V-A3	.0017	.162	.0054	.191	.0108	0.17	.0015
VI-A3	.0018	.253	.0088	.265	.0091	0.30	.0028
VII-A3	.0017	.233	.0062	.411	.0092	0.44	.0016
I-B1	.0021	.330	.0265	.151	.0450	0.22	.0030
II-B1	.0015	.253	.0050	.136	.0088	0.14	.0028
III-B1	.0019	.234	.0064	.178	.0063	0.41	.0022
IV-B1	.0017	.174	.0146	.133	.0064	0.32	.0029
V-B1	.0014	.259	.0094	.194	.0069	0.24	.0023
VI-B1	.0015	.478	.0070	.336	.0080	0.36	.0021
VII-B1	.0018	.267	.0102	.250	.0062	0.25	.0019
I-B2	.0017	.368	.0156	.137	.0562	0.18	.0014
II-B2	.0012	.197	.0039	.111	.0096	0.10	.0021
III-B2	.0016	.208	.0042	.166	.0084	0.33	.0015
IV-B2	.0017	.190	.0043	.138	.0079	0.32	.0016
V-B2	.0013	.271	.0050	.238	.0093	0.23	.0013
VI-B2	.0019	.440	.0118	.308	.0074	0.35	.0011
VII-B2	.0016	.320	.0064	.283	.0067	0.28	.0013
I-B3	.0020	.361	.0132	.159	.0402	0.19	.0016
II-B3	.0013	.242	.0064	.123	.0140	0.17	.0019
III-B3	.0017	.171	.0034	.182	.0110	0.45	.0016
IV-B3	.0013	.237	.0068	.137	.0083	0.20	.0013
V-B3	.0015	.254	.0066	.228	.0161	0.25	.0016
VI-B3	.0017	.289	.0050	.319	.0099	0.42	.0012
VII-B3	.0016	.312	.0094	.371	.0113	0.38	.0018

Table XXII. (continued)

Treat- ment	Ash	Crude Fiber	Ether Extract	Protein	N-free Extract	K	Na
I-C1	6.47	29.22	1.92	8.56	53.83	1.06	.754
II-C1	6.58	29.42	2.93	7.81	53.26	0.960	.930
III-C1	5.78	28.78	2.65	10.38	52.41	0.736	.944
IV-C1	5.70	30.32	3.57	10.75	49.66	0.772	.942
V-C1	6.57	28.70	3.19	9.63	51.91	1.24	.612
VI-C1	5.99	28.78	3.76	10.50	50.97	0.676	1.06
VII-C1	5.97	29.27	3.78	10.50	50.48	0.982	.880
I-C2	7.64	29.85	1.94	10.44	50.13	2.49	.328
II-C2	6.94	27.61	3.61	9.19	52.65	2.19	.406
III-C2	6.82	28.86	3.44	9.50	51.38	2.25	.406
IV-C2	6.64	30.13	3.04	9.63	50.56	2.21	.420
V-C2	7.04	28.52	3.06	8.81	52.57	2.28	.339
VI-C2	6.71	28.79	3.08	8.69	52.73	2.11	.440
VII-C2	6.76	29.45	2.76	9.56	51.47	2.16	.474
I-C3	7.34	28.95	1.89	9.19	52.63	2.57	.244
II-C3	7.40	28.28	2.80	9.13	52.39	2.59	.241
III-C3	7.16	28.00	3.51	8.63	52.70	2.46	.224
IV-C3	7.34	28.68	3.41	10.38	50.18	2.48	.262
V-C3	7.64	28.58	2.77	8.56	52.45	2.66	.170
VI-C3	7.52	29.45	3.12	9.06	50.85	2.63	.244
VII-C3	6.91	29.61	2.92	9.44	51.12	2.64	.262

Table XXII. (continued)

Treat- ment	B	P	Fe	Mg	Mn	Ca	Cu
I-C1	.0016	.442	.0098	.195	.0425	0.36	.0013
II-C1	.0018	.342	.0064	.192	.0097	0.47	.0016
III-C1	.0020	.400	.0084	.215	.0062	0.43	.0019
IV-C1	.0017	.361	.0078	.206	.0073	0.48	.0021
V-C1	.0023	.438	.0109	.415	.0182	0.50	.0016
VI-C1	.0026	.582	.0128	.450	.0068	0.48	.0019
VII-C1	.0021	.387	.0133	.412	.0062	0.45	.0021
I-C2	.0017	.540	.0098	.168	.0500	0.47	.0010
II-C2	.0017	.400	.0055	.181	.0128	0.36	.0012
III-C2	.0017	.480	.0062	.218	.0106	0.57	.0016
IV-C2	.0019	.349	.0074	.185	.0088	0.40	.0020
V-C2	.0020	.480	.0110	.320	.0153	0.54	.0015
VI-C2	.0019	.430	.0085	.398	.0099	0.55	.0015
VII-C2	.0022	.471	.0112	.410	.0088	0.70	.0016
I-C3	.0015	.459	.0092	.155	.0564	0.33	.0011
II-C3	.0015	.524	.0068	.191	.0218	0.43	.0017
III-C3	.0016	.519	.0066	.206	.0086	0.44	.0016
IV-C3	.0019	.294	.0069	.219	.0093	0.32	.0021
V-C3	.0019	.560	.0078	.340	.0178	0.46	.0013
VI-C3	.0022	.441	.0084	.327	.0105	0.48	.0013
VII-C3	.0020	.327	.0082	.373	.0086	0.44	.0019

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TABLE XXIII. Chemical Composition of Alfalfa*

Treat- ment	Ash	Crude Fiber	Ether Extract	Protein	N-free Extract	K	Na
I-0	---**	--	--	23.13	--	--	--
II-0	8.79	24.26	3.32	18.46	45.17	.582	.218
III-0	12.92	22.28	3.19	18.76	42.85	.656	.218
IV-0	9.78	23.56	3.54	18.59	44.53	.759	.193
V-0	9.47	24.12	3.32	19.82	43.26	.719	.197
VI-0	8.99	22.96	3.75	19.12	45.18	.746	.161
VII-0	8.21	23.93	3.93	18.73	45.20	.847	.143
I-A1	--	--	--	15.97	--	1.37	.134
II-A1	9.84	22.71	3.68	18.43	45.34	.968	.089
III-A1	8.31	23.95	3.79	19.23	44.72	.805	.140
IV-A1	9.00	23.26	3.15	19.73	44.87	.730	.211
V-A1	9.07	22.83	3.05	19.66	45.39	.833	.127
VI-A1	9.58	22.61	3.30	19.39	45.12	.778	.134
VII-A1	8.70	22.39	3.27	20.65	44.99	.720	.165
I-A2	--	--	--	15.03	--	2.05	.044
II-A2	9.69	22.46	3.42	18.80	45.63	1.80	.018
III-A2	8.78	21.76	3.69	19.85	45.95	1.83	.012
IV-A2	9.94	22.14	3.36	20.36	44.24	1.94	.020
V-A2	8.64	24.28	3.59	19.76	43.73	1.81	.017
VI-A2	9.43	22.09	3.36	20.11	45.01	1.58	.014
VII-A2	9.34	21.34	3.81	20.32	45.20	1.72	.025
I-A3	--	--	--	18.48	--	--	--
II-A3	10.23	22.49	3.51	18.91	44.86	1.95	.017
III-A3	9.65	22.17	3.44	19.85	44.89	1.95	.014

*Values expressed as percent

**Insufficient sample for a determination

Table XXIII. (continued)

Treat- ment	B	P	Fe	Mg	Mn	Ca	Cu
I-0	.0039	.59	.065	.48	.200	2.15	.0042
II-0	.0029	.31	.039	.42	.019	3.00	.0055
III-0	.0032	.31	.071	.37	.023	2.67	.0059
IV-0	.0018	.22	.032	.31	.016	3.02	.0046
V-0	.0031	.29	.049	.67	.018	2.00	.0054
VI-0	.0026	.20	.032	.68	.016	2.14	.0046
VII-0	.0017	.17	.029	.72	.013	2.05	.0044
I-A1	.0037	.36	.048	.42	.120	1.81	.0051
II-A1	.0029	.31	.050	.25	.018	2.45	.0051
III-A1	.0026	.33	.038	.25	.016	2.45	.0055
IV-A1	.0024	.44	.047	.25	.018	2.90	.0052
V-A1	.0027	.27	.040	.50	.018	1.75	.0051
VI-A1	.0029	.31	.053	.57	.020	2.15	.0060
VII-A1	.0025	.34	.050	.67	.018	2.58	.0045
I-A2	.0043	.42	.054	.22	.160	1.55	.0076
II-A2	.0031	.22	.036	.18	.017	2.15	.0052
III-A2	.0027	.36	.032	.15	.014	2.27	.0043
IV-A2	.0016	.21	.029	.11	.013	1.90	.0050
V-A2	.0024	.23	.025	.34	.013	1.45	.0050
VI-A2	.0018	.13	.019	.27	.010	1.32	.0046
VII-A2	.0015	.15	.019	.29	.011	1.32	.0039
I-A3	.0055	.34	.063	.27	.250	1.33	.0031
II-A3	.0020	.15	.025	.11	.009	1.34	.0054
III-A3	.0027	.29	.053	.17	.015	1.92	.0082

Table XXIII. (continued)

Treat- ment	Ash	Crude Fiber	Ether Extract	Protein	N-free Extract	K	Na
IV-A3	9.51	22.41	3.37	9.96	44.75	1.95	.014
V-A3	9.34	24.95	3.26	17.70	44.75	1.99	.013
VI-A3	9.36	22.90	3.27	18.78	45.69	1.95	.015
VII-A3	9.53	23.51	2.98	20.05	43.93	1.95	.015
I-B1	--	--	--	13.02	--	1.44	.111
II-B1	10.27	22.34	3.33	20.12	43.94	.793	.153
III-B1	8.89	23.38	2.97	20.25	44.51	.921	.140
IV-B1	9.02	24.16	2.28	19.23	45.31	.742	.252
V-B1	8.89	22.74	2.79	18.77	46.81	1.03	.069
VI-B1	10.65	23.57	2.83	19.94	43.01	.926	.111
VII-B1	8.61	22.72	3.27	20.23	45.17	.845	.111
I-B2	--	--	--	21.83	--	--	--
II-B2	10.05	22.63	3.32	19.80	44.20	1.85	.023
III-B2	9.12	22.31	3.31	19.23	46.03	1.79	.013
IV-B2	9.31	23.86	2.87	19.53	44.43	1.72	.023
V-B2	8.48	23.37	3.34	18.99	45.82	1.84	.017
VI-B2	9.39	23.70	2.99	20.13	43.79	1.79	.019
VII-B2	9.86	22.87	2.68	20.73	43.86	1.71	.017
I-B3	--	--	--	20.36	--	--	--
II-B3	11.88	23.80	2.91	19.10	42.31	2.21	.019
III-B3	9.75	21.81	3.07	19.34	46.03	2.09	.015
IV-B3	10.59	23.64	2.71	19.26	43.80	2.06	.013
V-B3	9.76	22.99	3.05	19.31	44.89	2.11	.017
VI-B3	8.98	22.63	3.09	19.42	45.88	1.96	.013
VII-B3	10.26	21.43	3.48	19.26	45.57	1.98	.014

Table XXIII. (continued)

Treat- ment	B	P	Fe	Mg	Mn	Ca	Cu
IV-A3	.0019	.29	.043	.13	.013	1.70	.0060
V-A3	.0026	.19	.031	.27	.015	1.61	.0072
VI-A3	.0022	.19	.030	.30	.014	1.92	.0081
VII-A3	.0014	.22	.031	.19	.012	1.45	.0070
I-B1	.0034	.27	.036	.18	.100	1.41	.0057
II-B1	.0021	.24	.038	.23	.023	2.17	.0048
III-B1	.0017	.24	.024	.26	.017	2.72	.0058
IV-B1	.0024	.26	.042	.49	.020	2.17	.0062
V-B1	.0018	.39	.033	.24	.020	3.13	.0070
VI-B1	.0021	.40	.050	.46	.018	2.10	.0070
VII-B1	.0016	.36	.028	.63	.014	2.42	.0065
I-B2	. --	--	--	--	--	--	--
II-B2	.0031	.36	.051	.20	.016	2.27	.0027
III-B2	.0034	.40	.049	.18	.015	2.64	.0031
IV-B2	.0019	.37	.040	.13	.013	2.38	.0026
V-B2	.0038	.40	.051	.40	.015	1.99	.0034
VI-B2	.0023	.31	.040	.35	.011	2.07	.0026
VII-B2	.0022	.31	.047	.39	.013	1.83	.0032
I-B3	.0030	.67	.065	.29	.260	1.30	.0016
II-B3	.0036	.35	.049	.13	.019	2.00	.0032
III-B3	.0032	.36	.038	.13	.012	2.25	.0036
IV-B3	.0022	.42	.044	.13	.014	2.83	.0034
V-B3	.0029	.35	.044	.31	.018	1.92	.0034
VI-B3	.0023	.32	.035	.31	.013	2.17	.0037
VII-B3	.0022	.42	.052	.28	.013	1.85	.0044

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Table XXIII. (continued)

Treat- ment	Ash	Crude Fiber	Ether Extract	Protein	N-free Extract	K	Na
I-C1	--	--	--	18.74	--	--	--
II-C1	9.13	23.79	3.72	17.87	45.49	.689	.168
III-C1	9.07	23.97	3.39	18.54	45.03	.898	.091
IV-C1	11.15	23.46	3.35	18.00	44.04	.659	.168
V-C1	9.74	24.18	3.46	20.51	42.11	.811	.183
VI-C1	10.61	24.16	3.00	19.47	42.76	.912	.084
VII-C1	9.05	23.16	3.90	19.87	44.02	.888	.117
I-C2	--	--	--	20.54	--	--	--
II-C2	10.09	22.87	4.05	19.13	43.86	1.85	.018
III-C2	9.77	23.26	3.88	18.98	44.11	1.88	.016
IV-C2	17.62	22.51	2.22	17.96	39.70	1.69	.016
V-C2	9.24	22.51	3.42	18.77	46.06	1.92	.009
VI-C2	13.76	22.63	2.71	18.72	42.18	1.80	.010
VII-C2	9.32	21.81	3.35	18.88	46.64	1.85	.013
I-C3	--	--	--	20.25	--	--	--
II-C3	9.43	24.19	3.29	17.63	45.46	2.09	.008
III-C3	12.25	24.31	2.19	20.34	40.91	2.24	.011
IV-C3	10.73	21.59	2.84	18.81	46.03	1.86	.015
V-C3	9.48	22.76	3.23	20.02	44.51	2.08	.013
VI-C3	10.34	22.78	3.33	19.38	44.17	2.00	.009
VII-C3	10.15	21.74	3.40	19.89	44.82	2.04	.008

Table XXIII. (continued)

Treat- ment	B	P	Fe	Mg	Mn	Ca	Cu
I-C1	.0037	.69	.065	.34	.290	2.13	.0025
II-C1	.0025	.40	.048	.27	.020	2.70	.0028
III-C1	.0030	.50	.060	.24	.017	3.40	.0029
IV-C1	.0026	.58	.065	.26	.025	4.67	.0034
V-C1	.0027	.43	.029	.48	.019	2.28	.0039
VI-C1	.0042	.45	.065	.69	.017	2.24	.0040
VII-C1	.0030	.47	.044	.70	.015	2.39	.0039
I-C2	.0031	.68	.056	.23	.370	1.50	.0024
II-C2	.0025	.42	.045	.16	.016	2.39	.0037
III-C2	.0020	.40	.046	.15	.016	2.02	.0033
IV-C2	.0032	.49	.120	.13	.029	2.25	.0025
V-C2	.0029	.33	.034	.29	.019	1.89	.0036
VI-C2	.0031	.44	.082	.33	.023	1.89	.0039
VII-C2	.0020	.30	.030	.34	.018	2.13	.0038
I-C3	.0027	.43	.096	.21	.070	1.36	.0078
II-C3	.0021	.17	.029	.14	.016	1.40	.0049
III-C3	.0021	.21	.071	.15	.012	1.28	.0054
IV-C3	.0017	.22	.050	.15	.012	1.91	.0066
V-C3	.0015	.13	.024	.19	.009	1.10	.0026
VI-C3	.0016	.19	.054	.24	.012	1.17	.0070
VII-C3	.0019	.23	.046	.28	.012	1.80	.0062

TABLE XXIV

Total Bases in Soybeans, Milliequivalents per 100 gms.

Treatment	Ca	Mg	Na	K	Total
I-0	65	40	2	26	133
II-0	59	28	2	19	108
III-0	63	28	2	21	114
IV-0	137	40	2	21	200
V-0	82	50	2	21	165
VI-0	103	61	2	19	185
VII-0	106	70	3	18	197
I-A1	46	29	2	28	105
II-A1	65	25	2	31	123
III-A1	102	27	3	25	157
IV-A1	93	30	2	27	152
V-A1	75	45	2	26	148
VI-A1	83	51	3	24	161
VII-A1	81	57	2	23	163
I-A2	40	24	2	30	96
II-A2	61	24	3	29	117
III-A2	77	26	3	30	136
IV-A2	80	26	3	30	139
V-A2	78	38	2	31	149
VI-A2	82	45	3	28	158
VII-A2	91	46	2	29	168
I-A3	38	27	3	34	102
II-A3	62	25	2	35	124
III-A3	104	27	2	36	169

Table XXIV. (continued)

Treatment	Ca	Mg	Na	K	Total
IV-A3	92	26	3	30	151
V-A3	70	36	2	33	141
VI-A3	81	45	3	32	161
VII-A3	93	47	2	31	173
I-B1	70	34	2	28	134
II-B1	70	33	2	25	130
III-B1	92	35	2	26	155
IV-B1	104	33	2	30	169
V-B1	61	41	2	28	132
VI-B1	65	47	2	24	138
VII-B1	72	56	3	22	153
I-B2	64	33	2	34	133
II-B2	92	31	2	32	157
III-B2	96	27	2	31	156
IV-B2	93	27	3	33	156
V-B2	64	42	2	30	138
VI-B2	70	46	2	29	147
VII-B2	72	40	3	31	146
I-B3	72	34	2	36	144
II-B3	67	24	2	33	126
III-B3	91	24	2	38	155
IV-B3	89	23	2	36	151
V-B3	74	39	3	35	149
VI-B3	58	38	3	34	133
VII-B3	70	50	3	34	157

Table XXIV. (continued)

Treatment	Ca	Mg	Na	K	Total
I-C1	54	35	3	29	121
II-C1	79	30	3	26	138
III-C1	93	33	3	21	150
IV-C1	90	29	3	22	144
V-C1	95	62	3	30	190
VI-C1	75	60	3	23	161
VII-C1	61	56	3	21	141
I-C2	48	30	3	33	114
II-C2	74	27	3	31	135
III-C2	84	27	3	32	146
IV-C2	77	24	3	32	126
V-C2	70	52	3	29	154
VI-C2	91	42	3	29	165
VII-C2	58	42	3	30	133
I-C3	63	27	3	36	129
II-C3	91	25	3	35	154
III-C3	99	25	3	37	164
IV-C3	78	29	3	35	145
V-C3	66	48	3	34	151
VI-C3	65	47	3	34	149
VII-C3	64	38	3	35	140

TABLE XXV.

Total Bases in Oats, Milliequivalents per 100 grams

Treatment	Ca	Mg	K	Na	Total
I-0	21.4	17.7	49.2	41.6	129.9
II-0	14.7	13.8	24.9	51.8	105.2
III-0	24.4	18.1	34.8	48.7	126.0
IV-0	18.9	13.3	35.9	44.8	112.9
V-0	6.0	17.6	30.8	52.6	107.0
VI-0	13.4	21.8	31.0	46.6	112.8
VII-0	38.4	32.9	29.5	47.4	148.2
I-A1	7.0	14.6	39.0	32.3	92.9
II-A1	21.4	14.2	35.1	42.8	113.5
III-A1	18.4	12.8	29.5	32.2	93.0
IV-A1	15.9	10.9	28.7	35.6	91.1
V-A1	5.0	15.4	35.1	32.4	87.9
VI-A1	17.9	25.8	34.1	34.8	112.6
VII-A1	22.9	27.6	32.8	40.9	124.2
I-A2	8.0	12.2	52.5	15.8	88.5
II-A2	9.5	10.3	54.4	16.3	90.5
III-A2	19.9	14.4	61.3	12.4	108.0
IV-A2	19.4	12.0	56.4	19.4	107.2
V-A2	6.5	18.8	57.6	13.7	96.6
VI-A2	17.9	29.6	53.6	21.4-	122.5
VII-A2	28.4	29.6	51.3	13.2	122.5
I-A3	8.0	13.0	73.3	4.3	98.6
II-A3	7.0	9.9	70.5	3.0	90.4

Table XXV. (continued)

Treatment	Ca	Mg	K	Na	Total
III-A3	17.9	13.4	71.5	2.7	105.5
IV-A3	22.9	12.9	71.2	4.8	111.8
V-A3	8.5	15.7	71.0	8.4	103.6
VI-A3	14.9	21.8	67.1	4.9	108.7
VII-A3	21.9	33.8	65.7	5.5	127.1
I-B1	11.0	12.4	33.6	35.8	92.8
II-B1	7.0	11.3	29.8	38.5	86.5
III-B1	20.4	14.6	32.3	35.9	103.2
IV-B1	15.9	10.9	30.5	39.8	97.1
V-B1	12.0	16.0	31.0	36.6	95.6
VI-B1	17.9	27.7	30.3	40.4	116.3
VII-B1	12.4	20.6	27.4	36.0	96.4
I-B2	9.0	11.3	67.2	12.6	100.1
II-B2	7.0	9.1	56.6	18.3	91.0
III-B2	16.5	13.7	60.0	17.0	107.3
IV-B2	15.9	11.4	58.9	17.4	103.6
V-B2	11.5	19.6	54.3	12.9	98.3
VI-B2	17.4	25.4	54.3	13.9	111.0
VII-B2	14.0	23.3	48.4	16.8	102.5
I-B3	9.5	13.1	64.6	10.3	97.5
II-B3	5.0	10.1	66.1	6.5	87.7
III-B3	22.4	15.0	66.9	7.1	111.4
IV-B3	9.8	11.3	64.4	7.0	92.7
V-B3	12.4	18.8	63.6	7.7	102.5

Table XXV. (continued)

Treatment	Ca	Mg	K	Na	Total
VI-B3	20.9	26.2	62.2	8.7	118.0
VII-B3	18.9	30.5	64.1	9.1	122.6
I-C1	17.9	16.1	27.2	32.8	94.0
II-C1	23.4	15.8	24.6	40.4	104.2
III-C1	21.4	17.7	18.8	41.1	99.0
IV-C1	23.9	17.0	19.8	41.0	101.7
V-C1	24.9	34.2	31.8	26.6	117.5
VI-C1	23.9	37.0	17.3	46.1	124.3
VII-C1	22.4	33.9	25.2	38.3	119.8
I-C2	23.4	13.8	63.8	14.3	115.3
II-C2	17.9	14.9	56.1	17.7	106.6
III-C2	28.4	17.9	57.6	17.7	121.6
IV-C2	19.9	15.2	56.6	18.3	110.0
V-C2	26.9	26.3	58.4	14.7	126.3
VI-C2	27.4	32.7	54.1	19.1	133.3
VII-C2	34.8	33.7	55.4	20.6	144.5
I-C3	16.4	12.8	65.9	10.6	105.7
II-C3	21.9	15.7	76.4	10.5	114.5
III-C3	21.9	17.0	63.1	9.7	111.7
IV-C3	15.9	18.0	63.6	11.4	108.9
V-C3	22.9	28.0	68.4	7.4	126.5
VI-C3	23.9	26.9	67.4	10.6	128.8
VII-C3	21.9	30.7	67.6	11.4	131.6

TABLE XXVI.

Total Bases in Alfalfa, Milliequivalents per 100 grams

Treatment	Ca	Mg	K	Na	Total
I-0	107.0	39.5	---	---	---
II-0	148.0	34.6	14.9	9.5	207.0
III-0	132.7	30.5	16.8	9.5	189.5
IV-0	150.0	25.5	19.5	8.4	203.2
V-0	99.9	55.2	18.4	8.6	182.1
VI-0	106.3	56.0	19.1	7.0	188.4
VII-0	101.9	59.3	22.6	6.2	190.0
I-A1	90.3	34.6	35.0	5.8	165.7
II-A1	121.8	20.6	24.8	3.9	171.1
III-A1	121.8	20.6	20.6	6.1	169.1
IV-A1	140.7	20.6	18.7	9.2	89.2
V-A1	87.3	41.1	21.3	5.5	155.2
VI-A1	107.0	46.9	19.9	5.8	179.6
VII-A1	128.2	55.2	18.4	7.2	209.0
I-A2	77.3	18.1	52.5	1.9	149.8
II-A2	107.0	14.8	46.1	0.8	168.7
III-A2	112.9	12.3	46.9	0.5	172.6
IV-A2	94.8	9.2	49.7	0.9	154.6
V-A2	72.3	28.0	46.3	0.7	147.3
VI-A2	65.9	22.2	40.4	0.6	129.1
VII-A2	65.9	23.9	44.0	1.1	134.9
I-A3	66.3	14.0	---	---	---
II-A3	66.8	9.2	49.8	0.7	126.5

Table XXVI. (continued)

Treatment	Ca	Mg	K	Na	Total
III-A3	95.8	14.0	49.8	0.6	160.2
IV-A3	84.8	10.8	49.8	0.6	146.0
V-A3	80.3	22.2	50.9	0.6	154.0
VI-A3	95.8	24.7	49.8	0.7	171.0
VII-A3	72.3	15.6	49.8	0.7	138.4
I-B1	70.4	14.8	36.9	4.8	126.9
II-B1	107.9	18.9	20.3	6.7	153.8
III-B1	135.1	21.4	23.6	6.1	186.2
IV-B1	107.9	40.3	19.0	11.0	178.2
V-B1	155.6	19.8	26.4	3.0	204.8
VI-B1	104.3	37.9	23.7	4.8	170.7
VII-B1	120.2	51.9	21.6	4.8	198.5
I-B2	---	---	---	---	---
II-B2	112.9	16.5	47.4	1.0	177.8
III-B2	131.1	14.8	45.8	0.6	192.3
IV-B2	118.2	10.7	44.0	1.0	173.9
V-B2	99.3	32.9	47.2	0.7	180.1
VI-B2	102.9	28.8	45.8	0.8	178.3
VII-B2	91.3	32.1	43.7	0.7	167.8
I-B3	64.8	23.9	---	---	---
II-B3	99.9	10.7	56.6	0.8	168.0
III-B3	111.9	10.7	53.5	0.7	176.8
IV-B3	140.7	10.7	52.7	0.6	204.7
V-B3	95.8	25.5	54.0	0.7	176.0
VI-B3	107.9	25.5	50.1	0.6	184.1

Table XXVI. (continued)

Treatment	Ca	Mg	K	Na	Total
VII-B3	92.3	23.1	50.6	0.6	166.6
I-C1	106.3	28.0	49.1	4.7	188.1
II-C1	134.9	22.2	17.6	7.3	182.9
III-C1	169.8	19.8	23.0	4.0	216.6
IV-C1	233.2	21.4	16.8	7.3	278.7
V-C1	113.8	39.5	20.8	8.0	182.1
VI-C1	111.9	56.9	23.3	3.4	195.5
VII-C1	119.3	57.6	22.7	5.1	204.7
I-C2	74.8	18.9	---	---	---
II-C2	119.3	13.2	47.4	0.8	180.7
III-C2	100.9	12.3	48.1	0.7	162.0
IV-C2	112.2	10.7	43.3	0.7	166.9
V-C2	88.9	23.9	49.2	0.4	162.4
VI-C2	94.4	27.2	46.1	0.4	168.1
VII-C2	106.3	28.0	47.3	0.6	182.2
I-C3	67.9	17.3	---	---	---
II-C3	69.8	11.5	53.5	0.4	135.2
III-C3	63.9	12.3	57.3	0.5	134.0
IV-C3	95.3	12.3	47.6	0.7	155.9
V-C3	54.9	15.6	53.2	0.6	124.3
VI-C3	58.4	19.8	51.1	0.4	129.7
VII-C3	89.9	23.1	52.2	0.4	165.6

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