THE EFFECT OF SOIL pH, AS MODIFIED BY LIMING, ON THE AVAILABILITY OF PHOSPHORUS AND POTASSIUM FOR ALFALFA IN SOME EASTERN ONTARIO SOILS

By

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A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Soil Science

1954

ACKNOWLEDGEMENTS

The author gratefully acknowledges the guidance and encouragement of Dr. R. L. Cook, and the constructive advice and interest of Dr. L. M. Turk. Grateful acknowledgement is made for the support of the Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service, and for the cooperation of the Division of Chemistry, Science Service, Canada Department of Agriculture.

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ABSTRACT

This investigation was undertaken as a result of an interest in the problem of liming slightly acid soils for growing alfalfa. Since this crop responds to phosphorus and potassium applications to many soils, the effect of different pH levels on the availability of these plant-nutrients was considered worthy of investigation.

Calcium hydroxide was added to pots containing six soils of eastern Ontario, to provide pH levels of approximately 5.5, 6.0, 6.5, 7.0, and 7.5 for three of the soils, and approximately 6.0, 6.5, 7.0 and 7.5 for the other three. Greenhouse and laboratory studies were conducted to learn the effect of pH on the yield and contents of phosphorus, calcium and magnesium in alfalfa, grown with no fertilizer and with phosphorus and potassium treatments applied singly and in combination

Analyses were made for mechanical composition, pH, organic matter, total nitrogen, exchange capacity and the exchangeable cation contents of the soils. The exchangeable hydrogen in the limed samples was determined and the values obtained along with those for exchange capacity were used to calculate the degree of base saturation of the soils after liming. Available phosphorus was extracted by four

methods, water-soluble magnesium and potassium, and exchangeable potassium were determined in the limed soils sampled at the time of seeding, whereas available phosphorus and exchangeable potassium were determined in the samples taken after harvest of the crop.

The soils varied in texture from loamy sand to clay, in organic matter from 3.65 to 5.04 per cent, in pH from 5.45 to 6.00, and in exchange capacity from 8.46 to 17.89 milliequivalents per 100 grams of soil.

Without applied phosphorus the yield of alfalfa was significantly higher in most instances at a pH of about 7.5 than at any lower pH level. In the presence of applied phosphorus, however, there was evidence that the optimum pH for alfalfa was reached at about pH 6.5 to 7.0, above which no further increase in yield occurred. The increasing phosphorus content of the alfalfa and the greater uptake of phosphorus by the plants with increasing pH of most of the soils, indicated that a pH of about 7.5 was most favorable for supplying either native or applied phosphorus to alfalfa.

Although soil reaction had only a slight effect on the amounts of phosphorus extracted by the Bray methods, the results for the Truog and sodium bicarbonate methods showed that liming to or slightly above the neutral point, increased the available phosphorus in most of the soils.

Where no phosphorus was applied, potassium content of the plants tended to decrease with increasing yield as the pH was raised, but there were several instances with applied phosphorus at the higher pH levels, where the potassium content of the plants was relatively constant in association with relatively constant yield.

Water-soluble and exchangeable potassium decreased slightly as a result of at least some of the lime treatments in most of the soils.

The results indicate that liming to at least the neutral point increased the availability of phosphorus without appreciably decreasing the available potassium in the soils.

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INTRODUCTION

The beneficial results obtained from the application of lime on acid soils, particularly where legumes are grown, have been recognized for many years. In addition to supplying calcium, application of lime may have indirect effects on the availability of plant-nutrient elements. The relationship of soil reaction and the availability of phosphorus and of potassium in soils, assumes particular importance in ascertaining the optimum amounts of lime that should be applied for legume crops.

The soils in the vicinity of Ottawa, Ontario, vary in reaction from medium acidity to slight alkalinity. There has been some uncertainty with respect to the advisability of applying lime on the slightly acid soils in this area. Accordingly, experiments were begun in the fall of 1951 to ascertain the effect of different soil pH levels on the yield as well as on the phosphorus and potassium contents of alfalfa grown in pot tests. In an attempt to evaluate the phosphorus and potassium status of the soils as influenced by liming and cropping, estimates of available phosphorus and potassium in the soils, were obtained.

11 HISTORICAL REVIEW

The results of many investigations present evidence that liming of acid soils increases the availability of phosphorus in soils.

Truog (1933) reported that it was desirable to lime acid soils to a pH level of at least 6.5 in order to better permit plants to feed upon the phosphates in the soil. He stated, that the soluble phosphates in the soil react with Goethite to form a basic iron phosphate of low availability to plants, when the soil acidity exceeds that represented by a pH of 6.5. It was suggested that the phosphate of basic iron phosphate tended to form calcium phosphate, when the pH level of the soil was raised to 6.5 or higher. This calcium phosphate was considered to be soluble enough in carbonic acid excreted by plant roots to supply the phosphate requirements of plants.

The effect of liming on the subsequent availability of native and applied soluble phosphorus in several Michigan soils was studied by Cook (1935). Readily available phosphorus was determined by the Truog (1930) method. He found that increasing the degree of base saturation resulted in significant increases in the amounts of readily available phosphorus in seven soils and slight increases in two other soils. With the same soils, lime helped to preserve the availability of added soluble phosphates. Heck (1935) studied the availability of native phosphorus in Hawaiian soils by extraction with the method of Truog (1930) except that the ratio of solvent to soil was 400:1. Out of 76 soils with pH values below 6.5, 54.0 per cent contained 25 p.p.m. or less of available phosphorus. On the other hand, in a group of 24 soils with pH values of 6.5 or higher, 54.2 per cent of the samples contained over 100 p.p.m. of available phosphorus.

Experiments conducted by Salter and Barnes (1935) provide considerable information relating to the availability of phosphorus as influenced by soil reaction. In a pot experiment, Sudan grass was grown on a silt loam soil which received applications of lime to adjust the soil reaction to pH levels of 6.0 and 7.0. The soil adjusted to a pH of 7.0 produced the greater yield of Sudan grass, and the crop contained 0.346 per cent phosphorus (P_2O_5) as compared with only 0.245 per cent for that grown on the soil with a pH of 6.0. The authors concluded that there was considerable increase in the availability of the native phosphorus in the soil when its reaction was increased from pH 6.0 to 7.0.

Results obtained in field experiments by Salter and Barnes (1935) indicated that liming increased the availability of phosphorus in the soil. In an experiment where corn, oats, wheat, clover and timothy were grown in rotation over a 40-year period, the regular liming of one-half of each plot, as it was planted to corn, was begun in 1900. Without lime, the pH of the soil was approximately 5.0, whereas the reaction of the soil receiving lime was raised to a pH of 7.5. On plots receiving nitrogen and potash but no phosphorus in the fertilizer, the regression lines for the yields of wheat and corn on time indicated an appreciable decline in yield over the 40-year period where no lime was applied. On the other hand, where the pH of the soil was raised to a pH of 7.5, the yields of wheat remained nearly constant and those of corn increased on the average from about 37 bushels per acre in the early years of the experiment to about 48 bushels, some 30 years later. The authors suggested that the availability of native soil phosphorus was increased sufficiently by liming to compensate for the depleting effects of crop removal. In another experiment conducted during an eight-year period, seven different hay crops were grown in a three-year rotation with corn and small grain on plots where the soil reaction was adjusted by liming to pH levels of 4.7, 5.2, 5.9, 6.8, and 7.4. It was found that adjusting the pH level of the soil to 7.4 resulted in yields on unphosphated portions of the plots approximately equal to those obtained where phosphorus was applied. Liming was believed to have increased the availability of native soil phosphorus and to have reduced the need for fertilizer phosphorus.

Based on the earlier work of Gaarder (1930), a study was made by Benne (1936) on the solubility of phosphorus in dilute solutions of H_3PO_4 when treated with varying amounts of different calcium compounds in systems adjusted to different pH levels. He found that Ca^{++} ions did not precipitate phosphorus from solution until the pH approached 5.5, and minimum solubility was not reached until thepH was nearly 7.5. Calcium supplied by a calcium saturated soil gave somewhat similar results to that obtained with $CaCO_3$ as a source of calcium in the system. The author suggested that phosphorus was precipitated by Fe^{+++} ions between pH 2 and 3, and by Al^{+++} ions between pH 3 and 4.

Albrecht and Smith (1940) studied the effect of different degrees of calcium saturation on the utilization of phosphorus by Korean lespedeza, sweet clover, blue grass and red top in pot tests. They reported that a larger share of applied phosphorus was recovered in the crops as the degree of saturation of the soil by calcium was greater. This greater recovery resulted more because of larger crop yields, however, than because of a higher concentration of phosphorus in the forage. MacIntire and Hatcher (1942) reported a beneficial effect of liming on the availability of monocalcium phosphate applied to a number of soil samples. The availability of the applied phosphorus was determined by the Neubauer procedure. In every case, the uptake of phosphorus by the rye on the limed samples, exceeded that obtained for the series receiving no lime.

Dunn (1943a) studied the effect of lime on the availability of plant nutrients in five Washington soils. He reported that soil phosphorus values as measured by the Neubauer procedure and by the method of Truog (1930) increased as the pH of the soil was adjusted by liming up to and slightly above the neutral point. In pot tests, where clover and alfalfa were grown, he found that lime applications increased the uptake of phosphorus by the crops. In another pot test where lime and gypsum treatments were applied to the soils to supply adequate amounts of calcium at two different pH levels, it was found that soil phosphorus was less available at low pH values. In a study with electrodialyzed colloids of two of the soils, the author found no influence of pH and lime upon phosphorus adsorption between the pH range of 5.5 and 7.0.

In pot tests on seven soils of the sugar belt of Natal and Zululand, Beater (1945) studied the effect of four rates of lime on the absorption of phosphorus by maize and sugar cane plants grown after the lime had effected the desired changes in soil reaction. He reported that preliming resulted in a 20 per cent increase in the concentration of phosphates in the crops on a dry matter basis. Bonnet (1947) investigated the effect of liming on the availability of phosphorus in a lateritic soil and on the phosphorus content of Para-Carib grass grown on this soil. Twenty-three months after lime was applied to plots to adjust the pH of the soil from 4.6 to 6.5, the available soil phosphorus, as extracted with sodium acetate solution buffered at pH 4.8, was determined. The sample with a pH value of 6.5 contained 56 p.p.m. of available phosphorus as compared with only 21 p.p.m. in the unlimed soil. He reported that the phosphorus content of the grass grown on the limed soil, was higher than that of the grass grown without lime.

Attoe and Truog (1950) observed that the response of hay crops to superphosphate applications on a Spencer silt loam declined over a six-year period. They attributed this to the increase in availability of native phosphorus as a result of liming the soil at the beginning of the experiment to a pH level of 6.5.

Using labeled phosphorus in two pot tests and in one field test, Neller (1953) found that increasing soil pH levels by additions of lime had little or no beneficial effect on the uptake of phosphorus by oats or millet. The lime comparisons were over a pH range of 5.6 to 6.8 for the pot tests and 5.4 to 5.7 for the field test. In one of the pot tests, additions of lime significantly reduced the content of total phosphorus in the crops. In the other pot test there was no effect on the content of total phosphorus in the plants. In the field test, there were no significant differences between the phosphorus contents of oats grown on plots receiving lime at rates of 500, 1000, and 1500 pounds per acre. These results are somewhat at variance with the evidence from many investigations which tended to indicate that liming acid soils increased the availability of phosphorus in the soil.

With respect to the influence of liming on the potassium status of soils and on the absorption of potassium by plants, the literature tends to be somewhat confusing.

Brown and MacIntire (1911), and Ames and Simon (1924) found more water-soluble potassium in unlimed soils than in limed soils. MacIntire, Shaw and Young (1930) conducted lysimeter studies which showed that lime repressed the solubility of soil potassium. Schollenberger and Dreibelbis (1930) reported that the exchangeable potassium content of limed soil was only slightly lower than that of unlimed soil. Wilson (1930) found that application of lime to different soils had no consistent effect on exchangeable potassium. Jenny and Shade (1934) and Dean (1936) suggested that the depressive effect of lime on the availability of potassium in soil may be due in part to the action of microorganisms. Gilligan (1938) reported that the sorption of potassium in a form not recoverable by leaching with ammonium acetate increased with increasing calcium saturation of two soils.

Peech and Bradfield (1943) made a critical review of the literature, and suggested that the apparent confusion concerning the effect of lime and magnesia on the soil potassium and on the absorption of potassium by plants was the result of failure to evaluate properly the experimental conditions under which the results were obtained and to distinguish the Ca-K interactions in the soil from those in the plant. They stated that the addition of lime to soils containing neutral salts of strong acids may have no effect, may decrease, or may increase the concentration of potassium in the soil solution depending on the initial degree of base saturation of the soil. They suggested that in the absence of neutral salts, the addition of lime, even insufficient in amount to neutralize all of the exchangeable hydrogen, will liberate the adsorbed potassium.

York, Bradfield and Peech (1953a) reported that relatively large amounts of potassium were fixed in non-exchangeable forms during moist storage as a result of adding calcium carbonate to acid Mardin silt loam and increasing the pH of the soil. They found no evidence that lime-induced potassium fixation was related to increased microbial activity. Additions of lime up to 78 per cent base saturation reduced both water-soluble and exchangeable potassium. They reported that gypsum increased water-soluble potassium but had no influence on exchangeable potassium.

A number of investigators including Brown and MacIntire (1911), Ehrenberg (1919), Salter and Ames (1928), Fonder (1929), Bledsoe (1929), and Stanford, Kelly and Pierre (1942), have observed that liming depressed the uptake of potassium by plants. Naftel (1937) reported that liming soils to different degrees of calcium saturation, decreased the potassium content of sorghum only slightly. Van Itallie (1938) found that liming an acid soil had but little influence on the absorption of potassium by a number of different crops. They reported that liming an acid soil from a pH of 4.4 to 7.3, resulted in a pronounced decrease in the potassium content of wheat and oats; a slight decrease in that of barley, sweet clover, and cowpeas;

and an increase in that of peanuts, tomatoes, Kentucky bluegrass, timothy, and redtop. Albrecht and Schroeder (1942) suggested that the degree of hydrogen ion saturation of colloidal clay has little effect on the availability of potassium, although the hydrogen ion mobilized calcium, magnesium and other cations into plants.

Pierre and Bower (1943) reviewed the literature concerning the relation between the relative concentration of cations in solution and their absorption by plants. They stated that potassium absorption by plants is usually decreased by the presence of high concentrations of other cations in solution. The ratio of other cations to potassium, and the plant species were considered to be dominant factors influencing the effect of various cations on the absorption of potassium by plants. They suggested that the high ratio of calcium and magnesium to potassium in the soil solution of the high-lime soils of Iowa was a contributing factor to the low availability of potassium in these soils.

Hunter, Toth and Bear (1943) grew alfalfa on a series of prepared soils having calcium and potassium in the exchange complex in initial ratios varying between 1:1 and 32:1. They reported that the yield decreased when the calcium content of the plant tissue exceeded 2 per cent, when the potassium content was below 1 per cent, or when the Ca-K ratio exceeded 4:1. They concluded, however, that alfalfa could adjust itself to wide variations in soil Ca-K ratios, and that normal growth was made at ratios varying between 1:1 and 100:1.

On acid soil receiving additions of lime to adjust the soil reaction from a pH of 4.6 to different levels up to 7.5, Lynd and Turk (1948) found that the potassium content of soybeans decreased markedly where the soil pH was 7.5, and that of white beans decreased with increasing rates of lime. The yields of both crops were increased with increasing soil pH levels up to 7.0, above which there was a pronounced decline in yield.

Chu and Turk (1949) employed pot cultures to study the effect of the degree of base saturation on the growth and mineral composition of certain crops grown in bentonite-sand mixtures, kaolin-sand mixtures and an illitic soil. They showed that only within a certain range of base saturation was the mineral composition of plants a function of the degree of base saturation. When the degree of base saturation was increased with the ratios between the exchangeable calcium, magnesium and potassium remaining constant, they found that the potassium content of the crops grown in montmorillinitic media increased appreciably at only the higher levels of total base saturation. In the kaolinitic media there were definite increases in the potassium content of the plants with increasing degrees of base saturation at the lower levels. In the illitic soil the potassium content of the plants was found to increase with increasing degrees of base saturation. The authors reported that relative to the H-ion as a standard, the Ca-ion and the Mg-ion tended to increase the potassium content of rye grown in montmorillonitic and kaolinitic media receiving the same treatments, whereas the K-ion showed the reverse effect on availability of calcium and magnesium. They observed that Ca and Mg ions exhibited a mutually repressive effect in the experiment.

Although additions of lime have been observed in many experiments to decrease the potassium content of plants, it does not necessarily follow that calcium depresses the absorption of potassium. Thus York, Bradfield and Peech (1953b) found that the addition of gypsum or sufficient lime to maintain free calcium carbonate increased the potassium content of alfalfa grown in a silt loam soil. The effect of lime and typsum on absorption of potassium was reported to be dependent on the influence of these calcium-materials on the concentration of potassium in the soil solution. The same authors (1954) reported that there was little evidence that calcium had any antagonistic effect on absorption of potassium by alfalfa, corn, Sudan grass, and sericea grown in pot tests with calcium and potassium treatments. They observed, however, that potassium greatly reduced absorption of calcium, magnesium and sodium.

Several investigators including Van Itallie (1938), Bear and Prince (1945), Lucas and Scarseth (1947), and Wallace, Toth and Bear (1948) have observed that the total number of equivalents of cations absorbed by many crops may be relatively constant despite wide variations in the absorption of the individual cations. York, Bradfield and Peech (1954) found that the sum of the cations in alfalfa was essentially constant, but this did not hold for corn, Sudan grass and sericea. They suggested that the sum of the cations in plants may or may not be constant, depending on liming and fertilizer treatments, and on yields.

III. REGION INVESTIGATED

A. Description of the Area

The area is located in the eastern part of the Province of Ontario, and lies between the Ottawa and St. Lawrence Rivers, as shown in Figure 1. Eastern Ontario forms a part of the St. Lawrence Valley Section of the Newer or Folded Appalacians Province as defined by Lobeck (1948).

The physiography of the area has been described by Chapman and Putnam (1940). The bedrock originated in Palezoic seas and consists of sandstones, dolomites, limestones and shales. The region was subjected to at least three glaciations. At the time of glaciation the region was depressed below sea level. As the front of the ice-sheet receded northward, the region became submerged in the marine waters of Gilbert Gulf, an arm of the Champlain Sea. When the glacier receded farther afield, the land gradually rose to its present level, causing a general recession of the marine waters. With the recession of the Champlain Sea, streams extended their courses seaward by eroding channels in the emerging marine deposits.

The nature of the deposits have been described in soil survey reports by Hills, Richards and Morwick (1944), and Matthews and Richards (1952). The marine deposits range from coarse stratified gravel and sand to layers of heavy clay.

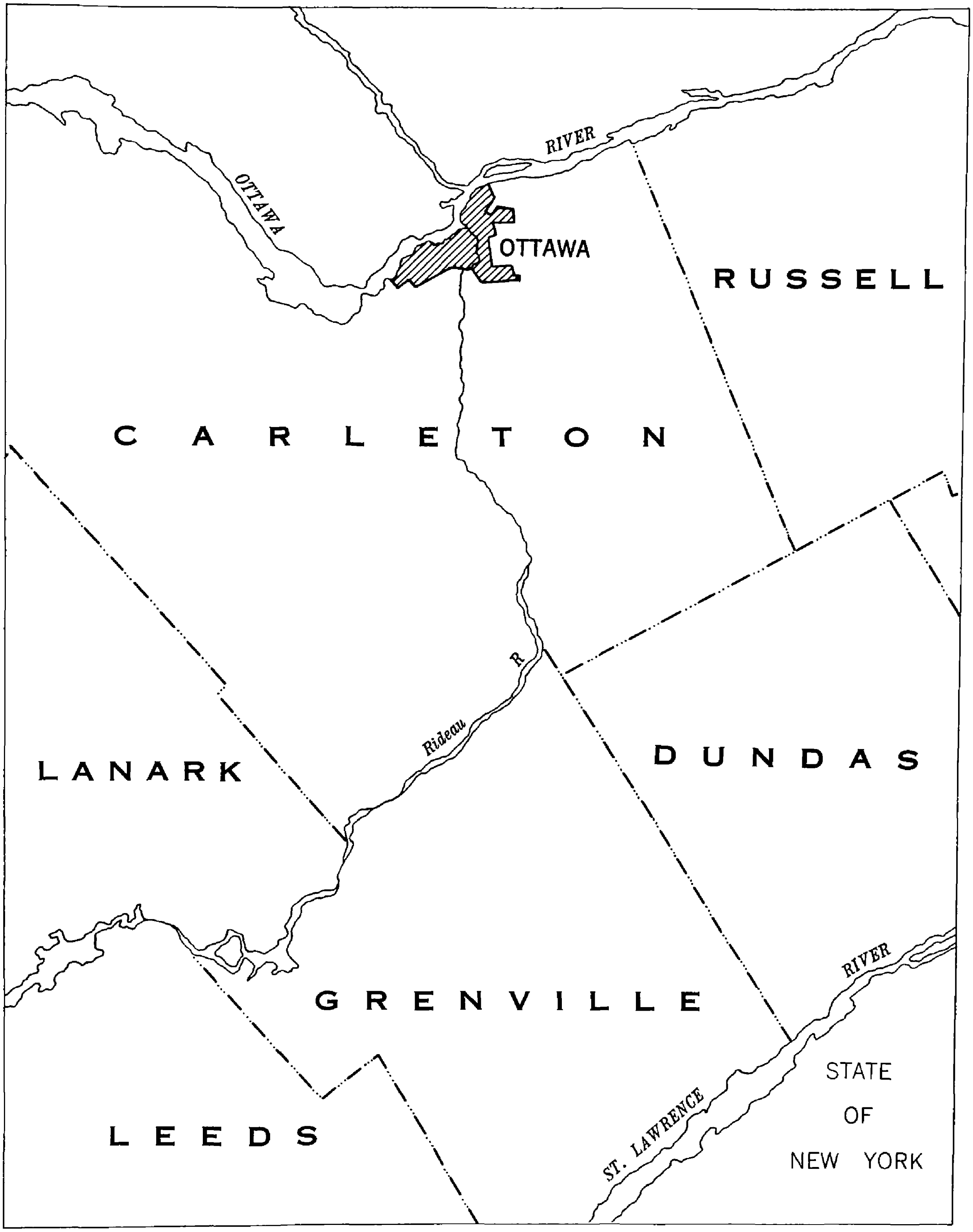

Fig.1 Sketch Map of Area from which Soil Samples were Obtained.

The coarse sands were usually deposited in fan-shaped areas where the waters of the streams were slowed up as they reached the sea. The finer sand, silt and clay were deposited in the deeper marine waters farther away from the mouths of the streams, according to the size of the particles. During the gradual recession of the sea, material was removed from the tops of the till and gravel ridges as soon as they were exposed, and this clay, silt, and sand was mixed with the clay materials settling from the marine water. These sediments are variable in chemical composition reflecting the different rocks from which they were derived. In addition to material from local ridges, siliceous and argillaceous materials low in lime content were brought in by streams from the north.

The topography of the area varies from level to gently rolling. Dairying and mixed farming are the main agricultural pursuits in the region. Cereal grains, ensilage corn, hay and pasture crops predominate in the acreage of field crops.

B. Description of Soils

The soils of the area occur within the grey-brown podzolic-podzol transition zone as described by Stobbe and Leahey (1948). The well-drained soils of this zone are reported to vary from weakly developed grey-brown podzolic soils on calcareous materials in the western section to well developed podzol soils on some of the non-calcareous materials. The soils were developed under a forest vegetation. The mean annual precipitation is about 34 inches. Some of the soils in the area have been described in soil survey reports by Hills, Richards and Morwick (1944) and by Matthews and Richards (1952). All of the soils described below were developed on water-laid materials.

1. Manotick Series

These soils are developed in well drained sandy materials underlain by clay, low in lime, at a depth of one and one-half to three feet. The internal drainage through the sandy materials is good, but when the water reaches the heavy clay, drainage is less rapid. The cultivated layer is a grey-brown sandy loam or loam. This soil series belongs to the brown podzolic great soil group. The topography ranges from moderate to strongly undulating.

2. Mountain Series

This soil is similar to the Manotick in all respects except that the drainage is imperfect.

3. Marionville Series

Soil of this series consists of twenty inches or less of fine sandy loam or silt materials over clay. In contrast to the Manotick and Mountain series, the Marionville soil does not have its profile developed entirely within the overlying lighter material. The underlying clay consists of grey and pink material low in lime similar to that of the Bearbrook series. The topography is level and drainage tends to be poor. This soil belongs to the dark grey gleisolic great soil group.

4. St. Thomas Series

This soil is a podzol developed on deltaic fine sand. The drainage tends to be excessive. The topography is undulating. The open nature of the subsoil and the low lime content favors the development of the podzol type of soil profile.

5. Bearbrook Series

This is a heavy clay soil, medium acid in reaction and with fair to poor natural drainage. The topography is level to gently undulating. The soil has developed from grey and pink clays low in lime. It belongs to the dark grey gleisolic great soil group. The structure of this soil tends to be faulty.

6. Rideau Series

This series is a very heavy soil, moderately drained and slightly to medium acid in reaction. The topography is gently undulating. The external drainage is moderate but the heavy clay layers restrict internal drainage. It is formed from water-laid grey clays low in lime. The development of this series has not advanced to the stage that would permit assigning it to any great soil group.

IV. EXPERIMENTAL

Surface samples of the six soils previously described were collected in the fall of 1951 for greenhouse and laboratory studies. The sample of Rideau soil was obtained from an oat field in Carleton County, whereas the samples of the other five soils were collected from sod fields in Russell County, Ontario. The soils of the latter county have been surveyed, but the map and report for this survey have not yet been published. The fields from which the samples were collected had received no lime so far as could be ascertained, and commercial fertilizers had not been used recently.

A. Greenhouse Studies

In the fall of 1951, a pot experiment was set up in the greenhouse at the Central Experimental Farm, Ottawa, Ontario. The soils were air-dried, passed through a screen with one-half inch mesh, mixed, and placed in glazed gallon pots. Ten pounds of air-dry soil was used in each pot.
Lime treatments. The amounts of lime required to raise the pH values of the soils to different levels up to pH 7.5 were determined from titration curves by the method of Dunn (1943b). On January 15-18, 1952, each of the amounts of calcium hydroxide (C.P.), as given in Table 1, was mixed with the soil in each of 16 pots for each of the pH levels desired. Soil moisture was adjusted as required by surface applications of water.

Fertilizer treatments. One month after the time of applying lime, a series of fertilizer treatments was applied to the soils at each pH level. The treatments were:

(1) Check.

(2) Potassium chloride at the rate of 200 pounds of K_2O per acre.

(3) Calcium dihydrogen phosphate at the rate of 200 pounds of P_2O_5 per acre.

(4) Treatment (2) plus treatment (3).

Calcium sulphate was applied with the calcium dihydrogen phosphate at the same rate as the latter salt, to simulate superphosphate, in treatments (3) and (4). The fertilizer and the lime treatments were randomized and replicated four times. The fertilizer materials were placed in a layer at a depth of two inches from the surface of the soil.

Seeding and harvesting. Grimm alfalfa was seeded on February 19, 1952. The seeds were placed in a layer at a depth of about one-third inch, and later the stand was thinned to ten plants per pot. The moisture in the soils was regulated by surface applications of water according to the observed requirements. Alfalfa in the bloom stage was harvested during the second week of June, the third week of July, the fourth week of August, and the first week of October in 1952. Yields were recorded on the air-dry basis, care being taken to weigh the crops on clear sunny days.

TABLE 1

LIME TREATMENTS USED IN POT EXPERIMENT

Soils	pH Desired	$Ca(OH)_2$ Added lb./acre
Manotick	5.5	0
	6.0	1800
	6.5	3800
	7.0	5800
	7.5	8200
Marionville	5.5	0
	6.0	1600
	6.5	3200
	7.0	5800
	7.5	8200
Bearbrook	5.5	0
	6.0	2400
	6.5	4000
	7.0	6800
	7.5	9600
St. Thomas	6.0	0
	6.5	2800
	7.0	5800
	7.5	8800
Mountain	6.0	0
	6.5	1400
	7.0	3800
	7.5	6200
Rideau	6.0	0
	6.5	800
	7.0	2400
	7.5	4600

B. Laboratory Studies

1. Analysis of Soils

Three sets of soil samples were obtained for analysis. These samples were:

(1) Samples of the soils retained at the time of potting, before any treatments were applied.

(2) Composite soil samples from the 16 pots representing each pH level at the time of seeding alfalfa, but prior to applying fertilizer treatments.

(3) Composite soil samples from the four pots representing each treatment after harvesting the last crop of alfalfa.

Samples of the air-dry soil were passed through a 2 m.m. screen. On the six samples representing the soils prior to applying any treatments, analyses were made for pH, total nitrogen, organic matter, exchange capacity, exchangeable cations, and mechanical composition. The samples taken at the time of seeding were analysed for pH, exchangeable hydrogen, exchangeable potassium, water-soluble potassium, easily soluble phosphorus and easily soluble magnesium. Easily soluble phosphorus and exchangeable potassium were determined on the samples taken after cropping.

The pH was determined by means of a glass electrode using a 1:2.5 soil-water ratio. The methods of Peech, Alexander, Dean, and Reed (1947) were used for the determination of exchange capacity, exchangeable bases and organic matter. In the determination of exchange capacity, the adsorbed ammonia was distilled after extraction with sodium chloride, and the micromethods were used for the determination of exchangeable bases. Exchangeable hydrogen was determined by the method of Schollenberger and Simon (1945). On the samples taken at the time of seeding, base saturation was calculated from the values for exchange capacity and exchangeable hydrogen.

The total nitrogen was determined by the Kjeldahl method as given by the Association of Official Agricultural Chemists (1945).

Mechanical analyses were performed by the hydrometer method of Bouyoucos (1951).

The water-soluble potassium was extracted using 50 grams of soil and 200 ml. of distilled water. The potassium in the extracts was determined by the method of Wilcox (1937).

Estimates of easily soluble magnesium were obtained using water and 0.013N acetic acid as extracting reagents. The magnesium was extracted with shaking for one minute, using 15 grams of soil and 60 ml. of extracting reagent. Magnesium was precipitated as magnesium ammonium phosphate after separation of manganese, iron, aluminium, phosphate, and calcium by the method of Peech, Alexander, Dean, and Reed (1947). The magnesium was determined from the phosphate content of the precipitate, using the method of King (1932). The readings for phosphorus were related to known concentrations of magnesium by means of a calibration curve.

Easily soluble phosphorus was determined by the methods of Truog (1930), Olsen, Cole, Watanabe, and Dean (1953), and Bray and Kurtz (1945). With the latter method the phosphorus in the extracts was determined according to the procedure described by Bray (1948).

2. Analysis of Plants

Composite samples of the plant material from the four harvests of alfalfa grown in the four replications of each treatment were prepared for analysis by grinding in a Wiley mill.

The plant samples were ashed by wet digestion with sulphuric, nitric and perchloric acids as described by Piper (1944). Phosphorus was determined by the method of King (1932). Calcium and potassium were determined by the methods of Peech, Alexander, Dean, and Reed (1947). Magnesium was precipitated as magnesium ammonium phosphate and determined using the method of King (1932) as described previously for easily soluble magnesium in the soil samples.

V. RESULTS AND DISCUSSION

A. Analysis of Soils

1. Physical and Chemical Properties of Soils

The results of analyses, showing some of the properties of the soils, are presented in Tables 11 and 111. On the basis of the classification of Stobbe and Leahey (1948), the soils varied in texture from loamy sand to clay as described in Table 11.

The Manotick, Marionville and Bearbrook soils had pH values of approximately 5.5, whereas the St. Thomas, Mountain and Rideau soils were slightly less acid with pH values varying from 5.88 to 6.0. The Manotick and St. Thomas soils, which had high sand contents, were quite similar in chemical properties. Both of these soils were relatively low in organic matter, nitrogen, exchange capacity, exchangeable bases and degree of base saturation, as compared with the other soils. The exchange capacity values for the Marionville, Bearbrook and Rideau soils were somewhat similar in magnitude and exceeded those obtained for the other soils. Comparison of the data for the different soils, indicates that the Ca:Mg ratios for the Manotick and St. Thomas soils were relatively high and the ratio for the Marionville soil was particularly low. The exchangeable potassium tended to increase with increasing amounts of clay in the soils.

TABLE 11

MECHANICAL ANALYSIS OF SOILS

Soils	Sand 2.0-0.05 m.m	Silt 0.05-0.002 m.m	Clay <0.002 m.m
	%	%	%
Manotick loamy sand	80.5	14.7	4.8
Marionville silt loam	17.2	71.6	11.2
Bearbrook clay loam	45.8	29.4	24.8
St. Thomas fine sandy loam	74.1	22.6	3.3
Mountain sandy loam	62.8	25.2	12.0
Rideau clay	18.0	40.6	41.4

TABLE 111

CHEMICAL ANALYSIS OF SOILS

Soils	Organic Matter	N	pH	Exchange Capacity	Exchangeable Cations*				Base Saturation
					Ca	Mg	K	H	
	%	%		m.e.	m.e.	m.e.	m.e.	m.e.	%
Manotick	3.65	0.13	5.63	8.46	2.35	0.29	0.12	5.31	32.6
Marionville	4.59	0.19	5.50	17.00	5.97	3.69	0.23	6.73	58.2
Bearbrook	4.34	0.21	5.45	16.11	5.58	1.89	0.32	8.16	48.4
St. Thomas	3.93	0.14	5.88	10.33	3.05	0.49	0.18	5.35	36.0
Mountain	5.04	0.20	5.95	12.57	6.13	1.59	0.29	4.51	63.7
Rideau	4.21	0.20	6.00	17.89	9.04	3.73	0.60	4.47	74.7

*In 100 grams of soil

TABLE 1V

REACTION AND BASE SATURATION OF SOILS AFTER LIMING

Soils	At Time of Seeding					After Last Harvest			
	pH		Exchangeable H		Base Saturation	pH in Different Fertilizer Series			
						Check	K	P	P+K
			m.e./100 gm.		%				
Manotick	5.53	5.58	5.50	5.62	34.3	5.66	5.60	5.43	5.43
	6.08	6.08	3.46	3.91	56.4	6.18	6.09	6.00	5.97
	6.55	6.58	2.77	2.32	69.9	6.56	6.52	6.48	6.40
	7.02	7.00	1.02	1.43	85.5	6.95	6.95	6.83	6.78
	7.48	7.45	0.00	0.00	100.0	7.47	7.43	7.41	7.39
Marionville	5.40	5.43	6.52	7.13	59.8	5.49	5.47	5.41	5.40
	5.91	5.87	4.40	4.89	72.6	5.94	5.92	5.74	5.73
	6.48	6.45	3.13	3.46	80.6	6.24	6.29	6.12	6.07
	7.01	7.00	1.34	1.91	90.4	6.80	6.82	6.72	6.72
	7.33	7.33	0.00	0.00	100.0	7.18	7.25	7.19	7.22
Bearbrook	5.30	5.22	7.50	7.50	53.4	5.29	5.30	5.22	5.14
	5.92	5.92	4.81	5.30	68.6	5.74	5.79	5.69	5.73
	6.35	6.35	3.38	3.71	77.9	6.15	6.16	6.06	6.09
	6.98	6.91	1.43	1.99	89.4	6.65	6.62	6.70	6.72
	7.45	7.42	0.00	0.00	100.0	7.26	7.30	7.26	7.26

TABLE 1V (continued)

Soils	At Time of Seeding					After Last Harvest			
	pH		Exchangeable H		Saturation	pH in Different Fertilizer Series			
						Check	K	P	P/K
			m.e./100 gm.		%				
St. Thomas	5.82	5.86	5.70	5.50	45.8	5.89	5.86	5.80	5.78
	6.42	6.50	2.85	3.26	70.4	6.49	6.48	6.43	6.33
	7.15	7.05	0.90	1.22	89.7	7.04	7.05	7.04	6.94
	7.50	7.55	0.00	0.00	100.0	7.48	7.49	7.44	7.42
Mountain	5.80	5.78	4.28	4.81	63.8	5.98	5.95	5.98	5.88
	6.35	6.32	2.85	3.13	76.2	6.33	6.32	6.20	6.22
	7.00	7.00	0.98	1.30	90.9	6.90	6.89	6.84	6.86
	7.50	7.60	0.00	0.00	100.0	7.36	7.37	7.40	7.36
Rideau	5.85	5.90	4.69	4.28	74.9	5.94	5.88	5.90	5.81
	6.15	6.15	2.77	3.13	83.5	6.06	6.07	6.04	6.03
	6.82	6.84	2.04	2.40	87.6	6.52	6.60	6.52	6.53
	7.36	7.39	0.00	0.00	100.0	7.12	7.16	7.11	7.10

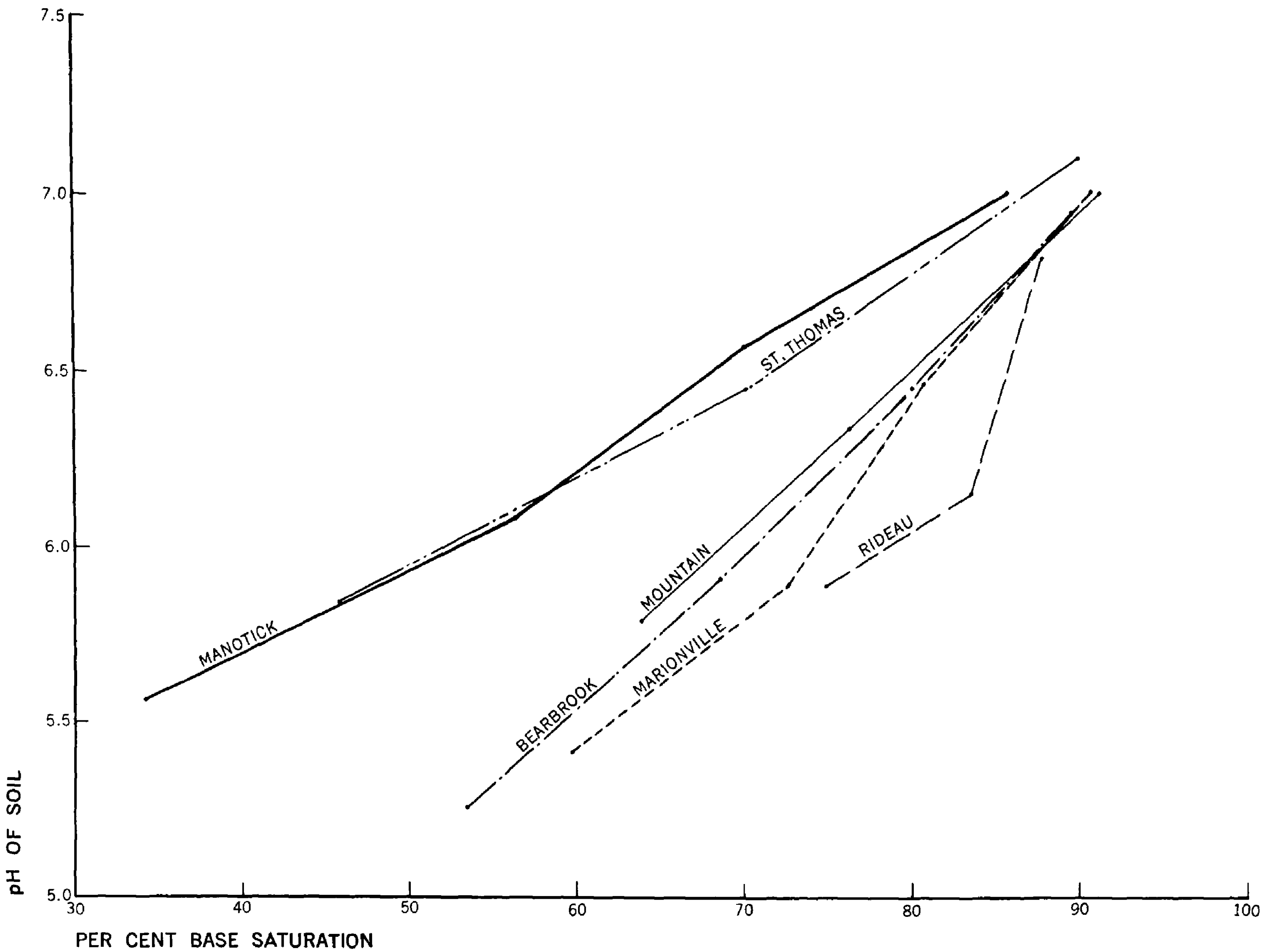

Fig.2. Relationship Between pH and Per Cent Base Saturation of Soils.

2. Reaction and Base Saturation of Soils after Liming

The data for reaction, exchangeable hydrogen and base saturation of the soils at the time of seeding alfalfa, as well as for the reaction of the soils after the final harvest of the crop, are presented in Table lV. The pH values of the soils at the time of seeding approached the levels intended for the rates of lime used. Following harvest of the alfalfa crops, the pH of the soils tended to be slightly lower than at the time of seeding.

The relationship between pH and the per cent base saturation of the soils is illustrated in Figure 2. The Manotick and St. Thomas soils which are sandy in texture, had relatively low values for per cent base saturation in the lower pH range, as compared with those shown for the soils of heavier texture.

B. Yields of Alfalfa in Pot Experiment

The data for the yield of alfalfa grown with different fertilizer treatments, at different pH levels established by liming, are presented in Table V. The effect of the different treatments on the yield is shown by the analyses of variance of the data for the different soils in Tables Vl to Xl, inclusive.

TABLE V

YIELDS OF ALFALFA GROWN WITH FERTILIZER TREATMENTS, AT DIFFERENT pH LEVELS ESTABLISHED BY LIMING

(Mean of four replications in grams per pot on air-dry basis)

Soils	pH of Soil	Fertilizer Treatments Check	K	P	P+K	L.S.D. (P.05)
		gm.	gm.	gm.	gm.	gm.
Manotick	5.56	9.5	13.1	28.9	38.0	
	6.08	11.0	14.5	29.6	45.6	
	6.57	14.1	18.6	30.0	47.7	
	7.01	19.0	24.5	31.6	51.0	
	7.47	21.2	29.9	32.1	49.2	4.0
Marionville	5.42	17.2	23.0	35.4	47.8	
	5.89	16.7	20.1	40.6	50.4	
	6.47	20.0	25.6	44.4	55.1	
	7.01	29.7	38.4	46.8	59.3	
	7.33	40.0	48.9	44.1	60.5	6.7
Bearbrook	5.26	39.3	44.3	48.1	58.4	
	5.92	46.9	49.7	66.3	72.6	
	6.35	47.9	57.7	70.3	76.9	
	6.95	62.0	66.4	75.1	75.1	
	7.43	70.6	71.4	75.9	73.9	6.4
St. Thomas	5.84	4.1	4.4	15.1	22.4	
	6.46	3.1	6.0	20.1	28.1	
	7.10	4.4	8.1	20.3	31.2	
	7.53	9.5	12.7	21.2	29.8	2.8
Mountain	5.79	26.8	30.2	34.5	48.4	
	6.34	33.9	41.1	48.0	61.0	
	7.00	48.4	57.7	55.5	71.2	
	7.55	54.2	70.0	63.1	74.1	6.7
Rideau	5.88	61.8	65.5	66.6	78.7	
	6.15	70.2	69.4	75.4	81.9	
	6.83	67.3	67.3	75.9	80.3	
	7.38	71.4	70.8	82.6	87.9	10.3

TABLE VI

ANALYSIS OF VARIANCE OF YIELDS OF ALFALFA ON MANOTICK SOIL

Source of Variation	Degrees of Freedom		Mean Square	F Value Obtained	Required P.05	P.01
Replications	3		76.2285	9.55	2.77	4.15
Fertilizers	3		3822.6568	478.73	2.77	4.15
P		1	8677.7780	1086.76	4.01	7.10
K		1	2211.3045	276.93	4.01	7.10
P x K		1	578.8880	72.50	4.01	7.10
Lime	4		313.3276	39.24	2.53	3.67
Lime vs. No Lime		1	624.1238	78.16	4.01	7.10
Rate of Lime		3	209.7289	26.27	2.77	4.15
Fertilizers x Lime	12		32.0970	4.02	1.93	2.52
P x Lime vs. No Lime		1	8.8777	1.11	4.01	7.10
K x Lime vs. No Lime		1	77.2575	9.68	4.01	7.10
P x K x Lime vs. No Lime		1	43.6053	5.46	4.01	7.10
P x Rate of Lime		3	70.5726	8.84	2.77	4.15
K x Rate of Lime		3	8.2518	1.03	2.77	4.15
P x K x Rate of Lime		3	6.3169			
Error	57		7.9850			

TABLE VII

ANALYSIS OF VARIANCE OF YIELDS OF ALFALFA
ON MARIONVILLE SOIL

Source of Variation	Degrees of Freedom		Mean Square	F Value Obtained	F Value Required P.05	F Value Required P.01
Replications	3		68.6173	3.09	2.77	4.15
Fertilizers	3		3441.0730	155.00	2.77	4.15
P		1	8376.3245	377.31	4.01	7.10
K		1	1772.8445	79.86	4.01	7.10
P x K		1	174.0500	7.84	4.01	7.10
Lime	4		918.1768	41.36	2.53	3.67
Lime vs. No Lime		1	1088.5501	49.03	4.01	7.10
Rate of Lime		3	861.3856	38.80	2.77	4.15
Fertilizers x Lime	12		91.3409	4.11	1.93	2.52
P x Lime vs. No Lime		1	5.1005			
K x Lime vs. No Lime		1	0.4205			
P x K x Lime vs. No Lime		1	0.5281			
P x Rate of Lime		3	332.2375	14.97	2.77	4.15
K x Rate of Lime		3	28.6358	1.29	2.77	4.15
P x K x Rate of Lime		3	2.4740			
Error	57		22.2004			

TABLE VIII

ANALYSIS OF VARIANCE OF YIELDS OF ALFALFA ON BEARBROOK SOIL

Source of Variation	Degrees of Freedom		Mean Square	F Value Obtained	F Value Required P.05	F Value Required P.01
Replications	3		19.5683			
Fertilizers	3		1370.8233	67.07	2.77	4.15
P		1	3726.4500	182.33	4.01	7.10
K		1	385.4420	18.86	4.01	7.10
P x K		1	0.5780			
Lime	4		1595.4884	78.06	2.53	3.67
Lime vs. No Lime		1	4455.1125	217.98	4.01	7.10
Rate of Lime		3	642.2804	31.43	2.77	4.15
Fertilizers x Lime	12		96.0672	4.70	1.93	2.52
P x Lime vs. No Lime		1	24.2000	1.18	4.01	7.10
K x Lime vs. No Lime		1	51.5205	2.52	4.01	7.10
P x K x Lime vs. No Lime		1	39.7620	1.95	4.01	7.10
P x Rate of Lime		3	278.0029	13.60	2.77	4.15
K x Rate of Lime		3	55.3621	2.71	2.77	4.15
P x K x Rate of Lime		3	12.4096			
Error	57		20.4382			

TABLE IX

ANALYSIS OF VARIANCE OF YIELDS OF ALFALFA ON ST. THOMAS SOIL

Source of Variation	Degrees of Freedom		Mean Square	F Value Obtained	Required P.05	P.01
Replications	3		3.5675			
Fertilizers	3		1759.8287	461.81	2.82	4.25
P		1	4620.6006	1212.53	4.06	7.23
K		1	505.1256	132.55	4.06	7.23
P x K		1	153.7600	40.35	4.06	7.23
Lime	3		131.9142	34.62	2.82	4.25
Lime vs. No Lime		1	266.0176	69.81	4.06	7.23
Rate of Lime		2	64.8609	17.02	3.21	5.11
Fertilizers x Lime	9		14.6382	3.84	2.10	2.83
P x Lime vs. No Lime		1	32.5064	8.53	4.06	7.23
K x Lime vs. No Lime		1	17.6442	4.63	4.06	7.23
P x K x Lime vs. No Lime		1	0.9652			
P x Rate of Lime		2	35.5409	9.33	3.21	5.11
K x Rate of Lime		2	3.5100			
P x K x Rate of Lime		2	1.2658			
Error	45		3.8107			

TABLE X

ANALYSIS OF VARIANCE OF YIELDS OF ALFALFA ON MOUNTAIN SOIL

Source of Variation	Degrees of Freedom		Mean Square	F Value Obtained	Required P.05	Required P.01
Replications	3		68.1663	3.11	2.82	4.25
Fertilizers	3		1417.7377	64.81	2.82	4.25
P		1	2184.3939	99.86	4.06	7.23
K		1	1990.2751	90.98	4.06	7.23
P x K		1	78.5439	3.59	4.06	7.23
Lime	3		2874.8863	131.42	2.82	4.25
Lime vs. No Lime		1	5558.8293	254.11	4.06	7.23
Rate of Lime		2	1532.9140	70.07	3.21	5.11
Fertilizers x Lime	9		47.0739	2.15	2.10	2.83
P x Lime vs. No Lime		1	9.0573			
K x Lime vs. No Lime		1	34.4261	1.57	4.06	7.23
P x K x Lime vs. No Lime		1	50.3266	2.30	4.06	7.23
P x Rate of Lime		2	113.2919	5.18	3.21	5.11
K x Rate of Lime		2	11.7606			
P x K x Rate of Lime		2	39.8756	1.82	3.21	5.11
Error	45		21.8755			

TABLE XI

ANALYSIS OF VARIANCE OF YIELDS OF ALFALFA
ON RIDEAU SOIL

Source of Variation	Degrees of Freedom	Mean Square	F Value Obtained	F Value Required P.05	F Value Required P.01
Replications	3	55.2562	1.05	2.82	4.25
Fertilizers	3	743.8853	14.11	2.82	4.25
P	1	1827.5625	34.67	4.06	7.23
K	1	236.3906	4.48	4.06	7.23
P x K	1	167.7025	3.18	4.06	7.23
Lime	3	274.8336	5.21	2.82	4.25
Lime vs. No Lime	1	573.3920	10.88	4.06	7.23
Rate of Lime	2	125.5539	2.38	3.21	5.11
Fertilizers x Lime	9	18.9026			
P x Lime vs. No Lime	1	15.8704			
K x Lime vs. No Lime	1	88.2923	1.67	4.06	7.23
P x K x Lime vs. No Lime	1	4.8093			
P x Rate of Lime	2	28.0732			
K x Rate of Lime	2	0.4694			
P x K x Rate of Lime	2	2.0320			
Error	45	52.7145			

The analyses of variance indicate that phosphorus and potassium treatments each resulted in significant differences in the yield of alfalfa on each of the soils. The interaction of phosphorus and potassium treatments was highly significant in the tests on Manotick, Marionville and St. Thomas soils. The differences between yields on the limed and unlimed soils were highly significant in all tests, and the differences resulting from the different rates of lime were highly significant for each of the soils except Rideau.

Of particular interest in this investigation, is the occurrence of any interaction effects between lime and phosphorus, or between lime and potassium treatments. Only on the light-textured Manotick and St. Thomas soils were there any significant interactions between lime and potassium treatments. On the other hand, the interaction of rates of lime on the phosphorus treatment was highly significant for each of the soils except Rideau. It is evident from the data in Table V, that the most beneficial pH level for alfalfa in the experiments, was dependent on the presence or absence of added phosphorus.

In the check and K series, the yields of alfalfa tended to increase with increasing pH levels established by liming. Considering all soils except Rideau, the yield of alfalfa for the highest pH level employed (approximately 7.5) in the check and K series, was significantly higher in most instances than that obtained at any lower pH level in these series. In the P and P/K series of the Manotick, Marionville, Bearbrook and St. Thomas soils, there was evidence that the optimum pH for alfalfa was reached at about pH 6.5 to 7.0. Except on the light-textured Manotick and St. Thomas soils, the yield in the series without applied phosphorus but on soil limed to a pH of about 7.5, was equal to or higher than that obtained in the corresponding series receiving phosphorus but no lime. These yield results are in agreement with those obtained with corn and small grains in field experiments by Salter and Barnes (1935).

C. Relationship of Soil Reaction and Phosphorus Supplying Power of Soils

1. Effect of Soil pH on Removal of Phosphorus by Alfalfa

The effect of lime, phosphorus and potassium treatments on the phosphorus content of alfalfa is shown by the data in Table Xll. The least significant difference between the means reported, based on the error of determination of the phosphorus in the plant ash, was 0.009 per cent. Application of phosphorus increased the phosphorus content of the alfalfa. Application of potassium which resulted in increased yields, tended to decrease the phosphorus content of the plants in most instances. In the series where no phosphorus was applied, the phosphorus content of the crop tended to decline slightly or to remain stationary until a pH of about

TABLE X11

PHOSPHORUS CONTENT OF ALFALFA, GROWN AT DIFFERENT pH LEVELS, WITH DIFFERENT FERTILIZER TREATMENTS (Mean of duplicate determinations on ash of composite samples, expressed as P on oven-dry basis)

Soils	pH	Fertilizer Treatments			
		Check	K	P	P/K
		%	%	%	%
Manotick	5.56	0.177	0.167	0.280	0.216
	6.08	0.185	0.146	0.288	0.234
	6.57	0.182	0.153	0.303	0.247
	7.01	0.181	0.157	0.304	0.263
	7.47	0.202	0.175	0.315	0.290
Marionville	5.42	0.225	0.201	0.319	0.292
	5.89	0.221	0.199	0.321	0.279
	6.47	0.229	0.207	0.344	0.297
	7.01	0.257	0.231	0.365	0.329
	7.33	0.274	0.264	0.396	0.367
Bearbrook	5.26	0.250	0.233	0.333	0.308
	5.92	0.215	0.207	0.303	0.294
	6.35	0.253	0.231	0.332	0.314
	6.95	0.283	0.266	0.356	0.351
	7.43	0.320	0.312	0.391	0.395
St. Thomas	5.84	0.168	0.166	0.255	0.231
	6.46	0.174	0.166	0.260	0.223
	7.10	0.193	0.162	0.262	0.232
	7.53	0.178	0.170	0.252	0.243
Mountain	5.79	0.287	0.256	0.333	0.310
	6.34	0.279	0.247	0.346	0.316
	7.00	0.309	0.269	0.352	0.346
	7.55	0.330	0.298	0.389	0.361
Rideau	5.88	0.272	0.272	0.327	0.316
	6.15	0.277	0.267	0.350	0.334
	6.83	0.296	0.292	0.348	0.343
	7.38	0.308	0.308	0.364	0.333

7.0 was reached in the Marionville, Bearbrook, Mountain and Rideau soils, and a pH of 7.47 in the Manotick soil. In all instances without applied phosphorus on these five soils, the highest phosphorus content of the alfalfa occurred at a pH of about 7.5. In the series where phosphorus was applied, the highest phosphorus content of the alfalfa occurred at a pH of about 7.5 in the Manotick, Marionville, Mountain and Bearbrook soils, although there was some decrease in the phosphorus content of the plants in the latter soil at the lower rates of liming. Where phosphorus was applied to the Rideau soil, the phosphorus content of the plants was increased as a result of liming, similar results being obtained from the different rates of lime. Soil reaction had no appreciable effect on the phosphorus content of the crop on St. Thomas soil.

The amounts of phosphorus taken up by alfalfa, as calculated from the yield and phosphorus content of the crop, are presented in Table X111. With few exceptions, the results indicate a pronounced increase in the uptake of phosphorus by the crop with increasing pH levels. Application of phosphorus consistently increased the uptake of phosphorus by the plants.

The separate effects of the pH of the soil on yield, phosphorus content, and uptake of phosphorus by the plants, are illustrated for five soil pH levels in Figure 3, and for four pH levels in Figure 4. The increasing phosphorus content of the plants associated with either increasing or relatively constant yields, as the pH of the soil was increased, in the Manotick, Marionville, Bearbrook, and Mountain soils in

TABLE X111

AMOUNTS OF PHOSPHORUS (P) REMOVED PER POT BY ALFALFA GROWN AT DIFFERENT pH LEVELS WITH DIFFERENT FERTILIZER TREATMENTS

Soils	pH	Fertilizer Treatments				L.S.D.*
		Check	K	P	P+K	(P.05)
		mgm	mgm	mgm	mgm	mgm
Manotick	5.56	15	20	74	75	
	6.08	19	19	78	98	
	6.57	24	26	83	108	
	7.01	32	35	88	123	
	7.47	39	48	93	131	
						8
Marionville	5.42	36	42	104	128	
	5.89	34	37	120	129	
	6.47	42	49	140	150	
	7.01	70	81	157	179	
	7.33	101	119	160	204	
						18
Bearbrook	5.26	90	95	147	165	
	5.92	93	95	185	196	
	6.35	111	122	214	222	
	6.95	161	162	246	242	
	7.43	208	205	273	268	
						18
St. Thomas	5.84	6	7	35	47	
	6.46	5	9	48	58	
	7.10	8	12	49	67	
	7.53	16	20	49	67	
						5
Mountain	5.79	71	71	106	138	
	6.34	87	93	153	177	
	7.00	137	143	179	226	
	7.55	164	192	226	246	
						19
Rideau	5.88	154	164	200	228	
	6.15	179	170	242	251	
	6.83	183	180	243	253	
	7.38	202	200	276	269	
						30

*Calculated from errors associated with means for yield and phosphorus content

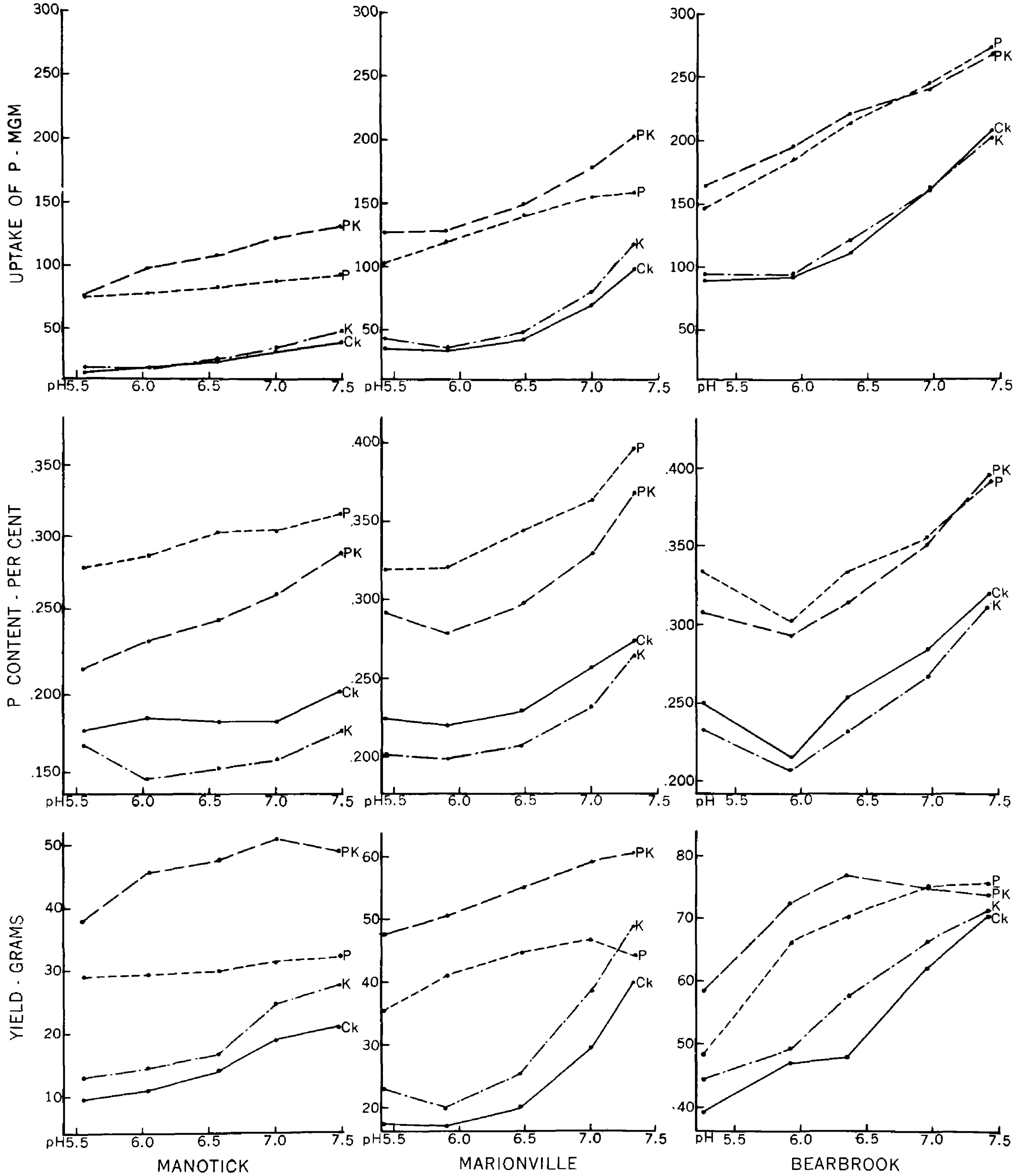

Fig.3 Effect of pH on Yield, Phosphorus Content, and Uptake of Phosphorus by Alfalfa, Grown on Three Soils at Five pH Levels in Different Fertilizer Series.

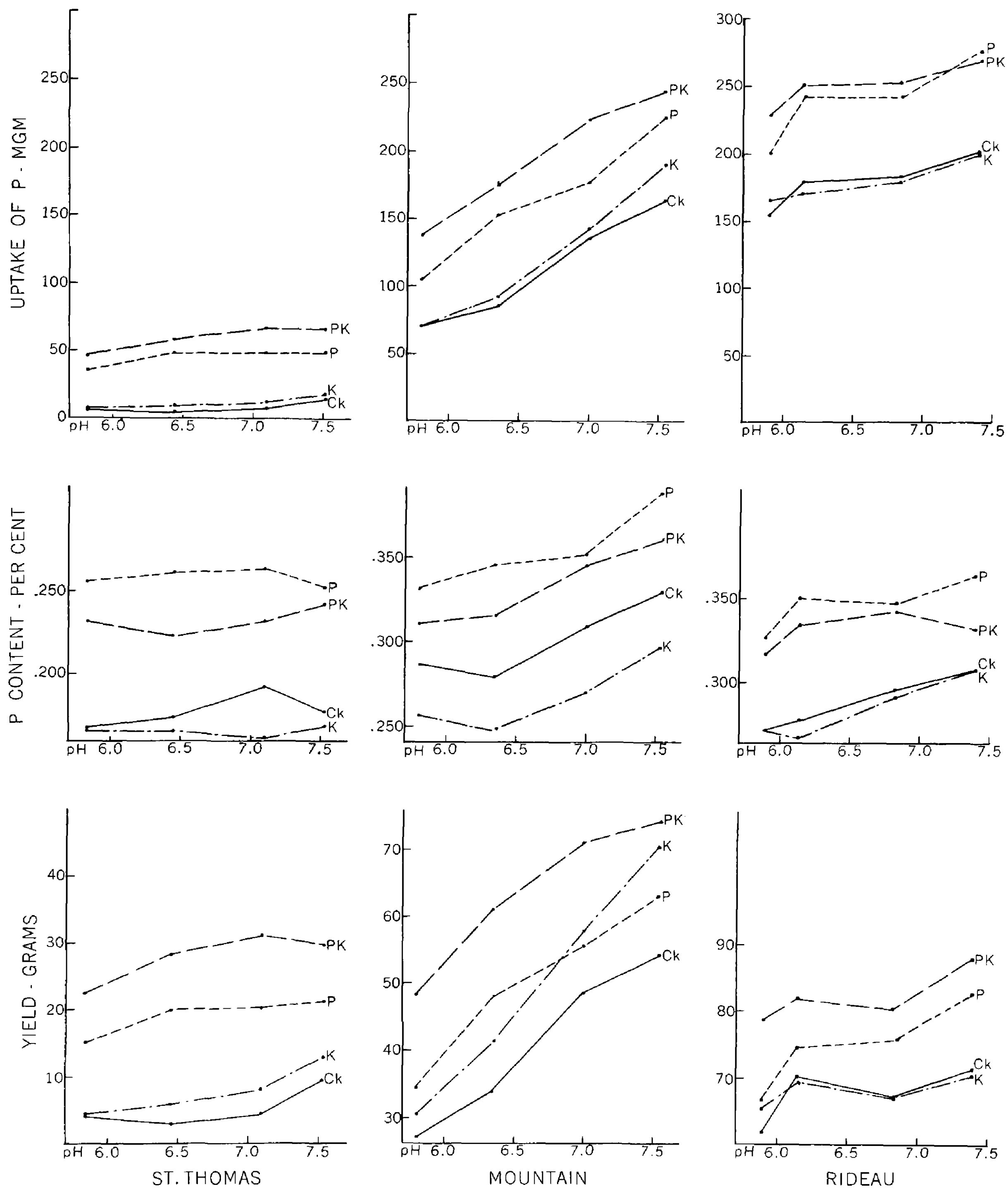

Fig.4 Effect of pH on Yield, Phosphorus Content, and Uptake of Phosphorus by Alfalfa, Grown on Three Soils at Four pH Levels in Different Fertilizer Series.

particular, provides evidence that a pH of about 7.5 was more favorable than any lower pH level investigated, for supplying either native or applied phosphorus to the plants. The results showing the beneficial effect of lime on the uptake of phosphorus by plants, are in agreement with those obtained by Dunn (1943a), Beater (1945) and Bonnet (1947) among others.

2. Effect of Soil pH on Amounts of Phosphorus Extracted by Different Chemical Methods

The amounts of available phosphorus in the soils prior to seeding and after harvest of alfalfa, are presented for the method of Truog in Table XlV, for the methods of Bray in Tables XV and XVl, and for extraction with sodium bicarbonate in Table XVll. As shown by the data in Table XVlll, the pH of the soil extracts obtained by the Truog and Bray methods tended to increase slightly with increasing pH levels in the soils, whereas the pH values for the sodium bicarbonate extracts were constant for all soil pH levels. The data indicate that the extracting reagent for adsorbed phosphorus was not as well buffered in the soils as were the reagents employed in the other methods.

The data in Table XlV obtained with the Truog method, show that the amounts of phosphorus in the samples of Manotick, Marionville, Bearbrook, and Mountain soils before seeding alfalfa, increased significantly with increase in the pH of the soils. The highest values for phosphorus oocurred

TABLE XlV

EFFECT OF SOIL pH ON AMOUNTS OF PHOSPHORUS
EXTRACTED BY THE TRUOG METHOD
(Mean of duplicate determinations as P on air-dry basis)

Soils	pH of Soil	Before Seeding	After Harvest of Crop on Different Fertilizer Series: Check	K	P	P/K	L.S.D.* (P.05)
		ppm	ppm	ppm	ppm	ppm	ppm
Manotick	5.56	3.9	3.2	1.9	3.8	5.2	
	6.08	4.7	4.5	3.5	6.0	6.0	
	6.57	5.5	4.8	4.8	10.5	7.2	
	7.01	7.0	6.4	4.3	13.0	8.6	
	7.47	7.9	7.3	5.2	14.6	10.7	
							1.2
Marion-ville	5.42	27.8	23.9	25.7	32.2	31.4	
	5.89	30.6	29.4	31.3	32.7	34.3	
	6.47	31.9	31.2	31.7	37.3	35.8	
	7.01	32.5	31.2	32.8	38.1	36.4	
	7.33	31.0	28.9	31.2	39.2	37.9	
							2.0
Bearbrook	5.26	23.7	17.8	18.0	23.9	21.3	
	5.92	25.8	20.2	20.7	25.1	22.8	
	6.35	29.4	22.0	21.7	26.0	26.4	
	6.95	33.9	24.0	24.0	31.5	30.4	
	7.43	34.5	25.0	23.4	35.3	35.5	
							2.0
St.Thomas	5.84	3.9	4.5	4.3	8.7	7.3	
	6.46	4.4	4.6	4.6	9.5	7.5	
	7.10	4.5	4.7	4.8	11.3	9.0	
	7.53	4.6	4.3	4.8	11.0	8.8	
							0.9
Mountain	5.79	35.5	27.1	27.1	39.8	31.5	
	6.34	34.6	27.2	26.2	38.1	33.5	
	7.00	38.7	27.6	28.4	38.5	36.6	
	7.55	38.3	29.5	28.9	42.3	39.5	
							2.4
Rideau	5.88	187.6	152.8	155.4	186.6	186.9	
	6.15	183.7	155.1	151.2	193.8	193.1	
	6.83	181.7	165.8	157.7	204.1	207.1	
	7.38	188.6	160.9	168.1	207.4	198.6	
							10.6

*Based on laboratory error only

TABLE XV

EFFECT OF SOIL pH ON AMOUNTS OF PHOSPHORUS EXTRACTED BY THE BRAY METHOD FOR ADSORBED PLUS ACID-SOLUBLE PHOSPHORUS (Mean of duplicate determinations as P on air-dry basis)

Soils	pH of Soil	Before Seeding	After Harvest of Crop on Different Fertilizer Series: Check	K	P	P+K	L.S.D.* (P.05)
		ppm	ppm	ppm	ppm	ppm	ppm
Manotick	5.56	25.0	24.3	22.9	34.3	31.1	
	6.08	22.5	23.8	22.7	35.7	34.0	
	6.57	23.8	20.8	20.8	39.8	33.3	
	7.01	23.4	21.0	20.8	39.9	32.4	
	7.47	24.6	20.7	20.3	37.9	31.5	
							2.4
Marion-ville	5.42	28.8	27.1	26.6	33.9	33.3	
	5.89	27.4	27.4	24.3	32.7	32.1	
	6.47	26.6	27.3	24.6	32.2	31.8	
	7.01	26.8	24.4	23.8	31.8	32.6	
	7.33	27.3	23.7	25.8	33.3	31.9	
							2.1
Bearbrook	5.26	37.5	29.5	29.2	38.7	37.1	
	5.92	37.0	29.0	27.4	36.6	36.8	
	6.35	38.0	26.7	26.2	35.2	35.2	
	6.95	38.6	27.5	26.3	38.1	37.7	
	7.43	39.2	26.1	24.8	38.2	37.5	
							2.7
St.Thomas	5.84	33.8	33.6	35.4	45.4	43.5	
	6.46	32.9	36.6	36.4	42.6	45.6	
	7.10	32.7	32.6	32.3	43.3	42.6	
	7.53	31.8	31.3	34.4	45.0	41.7	
							2.8
Mountain	5.79	39.8	31.3	29.0	53.1	40.4	
	6.34	38.0	27.3	27.6	43.6	37.9	
	7.00	38.8	28.3	26.2	42.2	37.8	
	7.55	40.9	27.5	25.6	41.1	39.6	
							2.8
Rideau	5.88	146.0	115.4	120.9	130.9	132.5	
	6.15	136.6	115.7	120.7	134.5	130.5	
	6.83	132.5	113.9	114.2	130.8	130.0	
	7.38	130.1	104.9	112.5	126.9	125.5	
							9.4

*Based on laboratory error only

TABLE XV1

EFFECT OF SOIL pH ON AMOUNTS OF PHOSPHORUS EXTRACTED BY THE BRAY METHOD FOR ADSORBED PHOSPHORUS
(Mean of duplicate determinations as P on air-dry basis)

Soils	pH of Soil	Before Seeding	After Harvest of Crop on Different Fertilizer Series: Check	K	P	P+K	L.S.D.* (P.05)
		ppm	ppm	ppm	ppm	ppm	ppm
Manotick	5.56	16.3	15.4	15.7	22.5	21.0	
	6.08	16.4	15.3	14.7	22.4	21.3	
	6.57	16.7	14.5	12.8	24.8	23.2	
	7.01	16.8	14.4	13.8	25.0	21.3	
	7.47	15.7	13.9	13.0	22.2	19.4	
							2.0
Marion-ville	5.42	11.2	7.0	7.0	12.8	11.6	
	5.89	10.6	7.5	7.7	12.9	10.4	
	6.47	12.6	7.9	7.5	12.8	10.7	
	7.01	13.2	8.2	8.3	14.5	11.6	
	7.33	15.1	8.5	8.2	15.7	11.8	
							2.1
Bearbrook	5.26	21.5	14.9	15.9	23.5	22.2	
	5.92	21.4	14.6	12.8	21.0	20.4	
	6.35	21.1	14.9	14.7	19.3	20.2	
	6.95	22.2	15.0	14.6	20.5	19.6	
	7.43	23.7	14.9	13.0	21.1	19.6	
							2.6
St.Thomas	5.84	14.6	14.4	15.7	20.1	19.1	
	6.46	13.7	14.0	14.8	19.4	18.4	
	7.10	12.7	13.8	13.8	17.5	17.2	
	7.53	14.1	14.3	14.4	15.1	15.4	
							2.7
Mountain	5.79	24.2	16.6	17.7	32.4	26.2	
	6.34	23.2	14.2	14.0	25.7	23.6	
	7.00	23.9	13.5	12.8	24.4	20.6	
	7.55	23.0	14.8	13.5	24.8	22.4	
							2.2
Rideau	5.88	35.5	22.5	23.4	30.7	27.2	
	6.12	36.4	23.4	24.7	30.5	28.0	
	6.83	38.2	22.2	23.0	32.9	30.2	
	7.38	41.2	22.0	23.2	30.5	26.2	
							4.6

*Based on laboratory error only

TABLE XV11

EFFECT OF SOIL pH ON AMOUNTS OF PHOSPHORUS DETERMINED BY EXTRACTION WITH SODIUM BICARBONATE
(Mean of duplicate determinations as P on air-dry basis)

Soils	of Soil	Before Seeding	After Harvest of Crop on Different Fertilizer Series: Check	K	P	P+K	L.S.D.* (P.05)
		ppm	ppm	ppm	ppm	ppm	ppm
Manotick	5.56	6.0	5.4	5.6	7.7	8.3	
	6.08	5.2	4.9	5.4	7.0	7.2	
	6.57	5.1	4.3	4.2	7.5	7.1	
	7.01	5.7	4.7	4.7	7.6	7.3	
	7.47	6.2	5.1	4.8	8.0	6.9	
							0.5
Marion-ville	5.42	7.6	6.4	5.8	10.9	9.3	
	5.89	7.1	5.9	5.4	9.3	8.8	
	6.47	7.6	5.5	5.6	10.8	9.2	
	7.01	9.3	5.2	6.3	10.8	9.0	
	7.33	10.4	6.2	6.6	14.0	10.1	
							0.8
Bearbrook	5.26	11.8	8.0	7.2	12.0	12.0	
	5.92	10.3	7.8	6.8	11.2	10.1	
	6.35	10.9	7.2	6.3	10.3	10.3	
	6.95	13.6	7.9	6.5	11.8	11.6	
	7.43	15.9	8.7	7.5	13.7	13.9	
							0.5
St.Thomas	5.84	4.4	4.2	4.8	6.6	6.4	
	6.46	4.5	4.0	3.8	5.6	5.2	
	7.10	4.2	4.1	3.8	5.6	5.3	
	7.53	4.9	4.3	4.8	6.1	5.6	
							0.5
Mountain	5.79	12.9	9.6	9.3	16.4	12.5	
	6.34	12.8	8.8	8.2	13.4	12.1	
	7.00	14.6	8.9	8.3	13.0	12.1	
	7.55	17.0	9.7	8.9	15.7	14.1	
							0.4
Rideau	5.88	20.8	11.9	11.8	21.3	19.7	
	6.15	21.0	11.5	11.2	17.4	18.4	
	6.83	23.4	12.3	12.1	19.7	21.3	
	7.38	28.6	12.5	12.5	20.0	22.2	
							1.1

*Based on error for determination of phosphorus in single extractions

TABLE XV111

EFFECT OF SOIL REACTION ON pH OF SOIL EXTRACTS OBTAINED BY THE METHODS USED IN THE EXTRACTION OF PHOSPHORUS

Soils	pH of Soil	pH of Soil Extracts			
		Truog Method (pH 3.00)*	$NaHCO_3$ Method (pH 8.5)*	Bray Methods	
				Adsorbed ≠ Acid-soluble (pH 1.21)*	Adsorbed (pH 3.07)*
Manotick	5.56	3.05	8.6	1.32	3.75
	6.08	3.10	8.6	1.35	3.85
	6.57	3.12	8.6	1.46	3.85
	7.01	3.18	8.6	1.41	3.88
	7.47	3.22	8.6	1.42	3.96
Marion-ville	5.42	3.08	8.6	1.42	3.67
	5.89	3.10	8.6	1.43	3.76
	6.47	3.12	8.6	1.42	3.78
	7.01	3.18	8.6	1.43	3.81
	7.33	3.20	8.6	1.45	3.88
Bearbrook	5.26	3.15	8.6	1.38	3.69
	5.92	3.07	8.6	1.40	3.67
	6.35	3.13	8.6	1.41	3.70
	6.95	3.13	8.6	1.42	3.72
	7.43	3.23	8.6	1.42	3.79
St.Thomas	5.84	3.10	8.6	1.45	4.50
	6.46	3.12	8.6	1.50	4.60
	7.10	3.21	8.6	1.52	4.60
	7.53	3.28	8.6	1.58	4.70
Mountain	5.79	3.08	8.6	1.38	3.50
	6.34	3.11	8.6	1.39	3.56
	7.00	3.12	8.6	1.39	3.65
	7.55	3.18	8.6	1.40	3.72
Rideau	5.88	3.11	8.6	1.42	3.65
	6.15	3.12	8.6	1.42	3.68
	6.83	3.18	8.6	1.42	3.71
	7.38	3.21	8.6	1.45	3.80

*Values obtained on extracting solutions used at a pH of approximately 7.0 or 7.5. Although larger amounts of phosphorus were removed by the crop with increase in pH values as shown previously, the limed soils contained more easily soluble phosphorus by the Truog method after harvest of the crop than was found in the unlimed samples. This was particularly true in the presence of applied phosphorus, where the values for extracted phosphorus increased with increase in pH values up to 7.0 or 7.5 approximately. Where no phosphorus was applied, the Truog values for easily soluble phosphorus in the soils after harvest of the crop, tended to be lower than the corresponding values found prior to seeding, and were consistently lower than the corresponding values found in the series where phosphorus was applied. The results obtained with the Truog method show that liming the soils to at least the neutral point, resulted in an increase in the availability of native and applied phosphorus.

As shown by the data in Table XV, soil pH did not have an appreciable effect on the amounts of adsorbed plus acid-soluble phosphorus determined by the method of Bray. The phosphorus values for the Rideau soil decreased slightly with liming. The unlimed soils, from which less phosphorus was removed by the crop, seemed to contain more phosphorus than did the limed soils, particularly where no phosphorus was applied. In most instances, the results for adsorbed plus acid-soluble phosphorus reflected the removal of phosphorus by the crops as well as the addition of phosphorus to the soils.

The results in Table XVl indicate that soil reaction had no pronounced effect on the amounts of the adsorbed form of phosphorus in the soils. There were, however, trends for this form of phosphorus to increase slightly at pH levels of about 7.0 or 7.5 in the samples obtained prior to seeding alfalfa on the Marionville, Bearbrook, and Rideau soils. Following harvest of the alfalfa, there was some decline in the amounts of adsorbed phosphorus in the Mountain and St. Thomas soils in the presence of applied phosphorus, as a result of liming. As pointed out previously, however, the plants removed more phosphorus from the limed soils. Where no phosphorus was applied, the values for the adsorbed form of phosphorus decreased with cropping on all soils except St. Thomas, and were lower than the corresponding values found for the soils where phosphorus was applied.

The data in Table XVll show a very consistent trend toward a decline in the amounts of phosphorus extracted with sodium bicarbonate as a result of the lower rates of lime, and for this to be followed by a rise in the phosphorus values at the higher pH levels. Except for the light-textured Manotick and St. Thomas soils, the samples obtained prior to seeding alfalfa contained appreciably more phosphorus when limed to a pH of about 7.0 and more particularly to about 7.5, than was found in the unlimed soils. In the series where no phosphorus was applied, the values for sodium bicarbonate-soluble phosphorus in the soils, limed to a pH of 7.5, were similar to those obtained for the corresponding unlimed soils, despite the greater removal of phosphorus by the crops on the limed soils. Where no phosphorus was applied, the values for soil phosphorus decreased as a result of cropping, and were consistently lower than in the series where phosphorus was applied. The results for sodium bicarbonate-soluble phosphorus showed that native and applied phosphorus were more available in soils limed to slightly above the neutral point.

The relationship prior to seeding between soil reaction and the amounts of phosphorus extracted with the procedures used, is further illustrated in Figure 5. The beneficial effect on the availability of native and applied phosphorus obtained from liming the soils to neutrality or slightly above, as shown by the results for the Truog and sodium bicarbonate methods, is in agreement with the greater uptake of phosphorus by the plants at a pH of about 7.5. Results obtained by Cook (1935), Heck (1935) and Dunn (1943a), indicated that the values for soil phosphorus by the Truog method increased with increasing pH of the soil towards or slightly above neutrality. Olsen, Cole, Watanabe and Dean (1935) suggested that the repression of the calcium ion activity by the addition of carbonate ions as in the sodium bicarbonate method, should have certain advantages over acid reagents in extracting calcium phosphate from soils varying in calcium carbonate content. In the present investigation, traces of carbonate

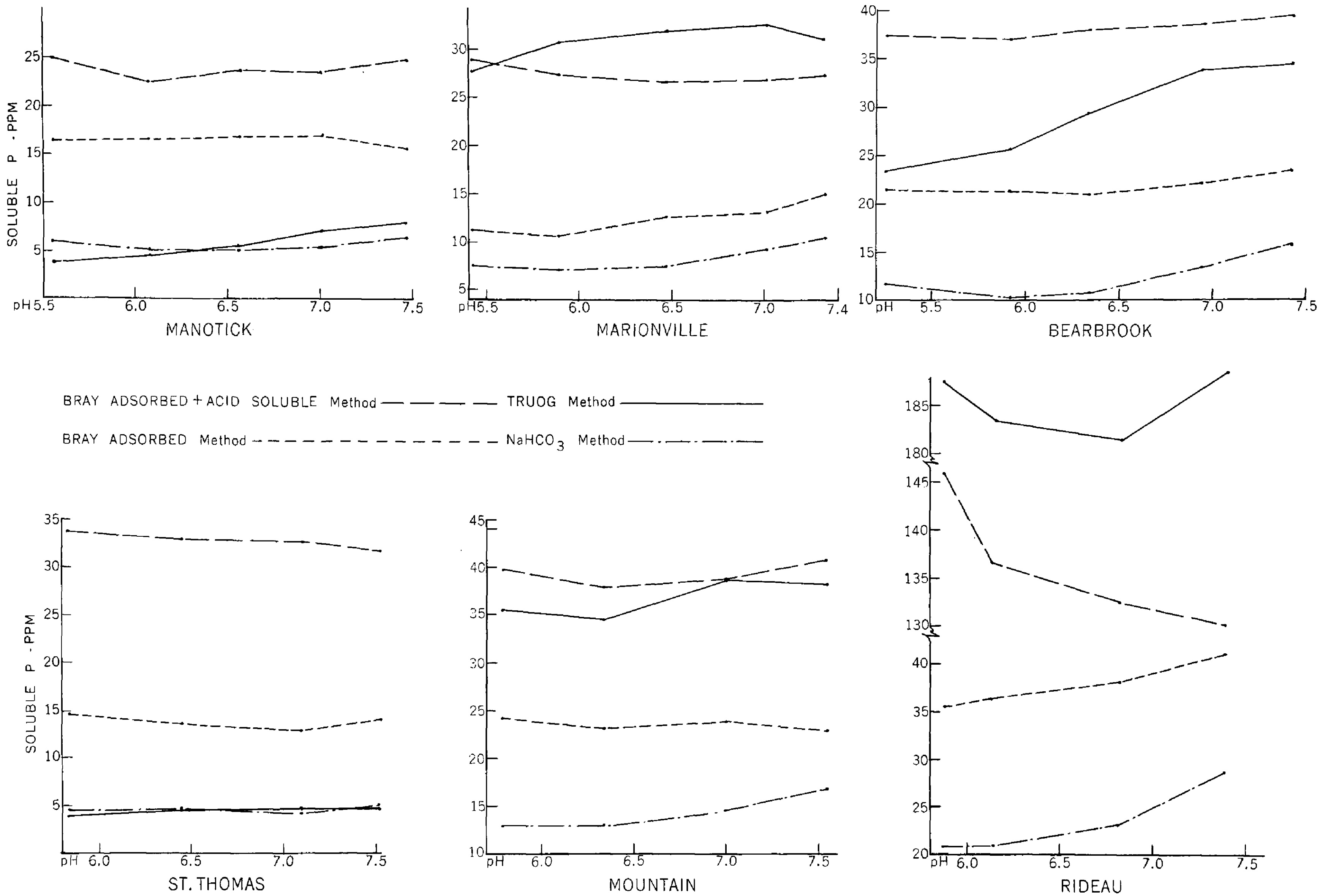

Fig.5 Relationship between Soil Reaction and Amounts of Soil Phosphorus Extracted by Different Methods.

were detected in some of the samples limed to the higher pH levels. With few exceptions, the results obtained with the Bray methods did not reflect the greater availability of soil phosphorus at the higher pH levels shown by the other chemical methods as well as by the results for uptake of phosphorus by the plants. Bray and Kurtz (1945) report that below a pH of 6.0 in cornbelt soils, the adsorbed forms of phosphorus are relatively more abundant than at higher pH values. In this investigation, however, the only trends for increase in Bray phosphorus values with increase in pH occurred for the adsorbed form of phosphorus as reported for the Marionville, Bearbrook and Rideau soils. Nevertheless, the results for the Bray methods reflected the removal of phosphorus by the crop. MacLean, Bishop, and Lutwick (1953) have reported data, based on a study of 90 soils in the Ottawa area, which showed that the results for the Bray methods were better correlated with the uptake of phosphorus in greenhouse tests, than were the results obtained with the Truog method.

3. Effect of Soil pH on Relationship between Phosphorus and Magnesium

Since one of the functions usually ascribed to magnesium is that of a carrier of phosphorus in the plant, the ratio of these two plant-nutrients in the alfalfa as influenced by liming, merits consideration. The Mg-P ratios within the alfalfa grown with different fertilizer treatments at varying pH levels, as well as the amounts of easily soluble magnesium in the soils following liming but prior to seeding, are presented in Table XlX.

The results show a rather consistent trend for the Mg-P ratios in the plants to decrease with increasing pH of the soil. In most instances the ratios within a particular pH level were lower where potassium was applied than in the corresponding series without potassium. Since the phosphorus content of the alfalfa tended to be lower in the two series where potassium was added, as shown previously (Table Xll), it would appear that the absorption of magnesium was repressed by the addition of potassium. The relatively lower ratios in the presence of added phosphorus were expected on the basis of the higher phosphorus content of the plants where phosphorus was added. The influence of liming and fertilizer treatments on the absorption of magnesium by the crop will be referred to later in a discussion of the cation content of the plants. From the declining Mg-P ratios, however, it is apparent that the increasing absorption of phosphorus with increasing pH, was not accompanied by any corresponding increase in absorption of magnesium by the plants.

The values for water-soluble magnesium as well as those obtained by extraction with 0.013N acetic acid, provide some basis for evaluating the relationship between pH and the soluble magnesium in the soils, which might be expected to be available

TABLE XIX

EFFECT OF SOIL pH ON MAGNESIUM-PHOSPHORUS RATIOS WITHIN ALFALFA PLANTS, AND ON EASILY SOLUBLE MAGNESIUM IN SOILS

Soils	pH After Liming	Mg-P Ratios in Plants*				Soluble Mg in Soils	
		Check	K	P	P+K	Water	0.013N HAc
						ppm	ppm
Manotick	5.56	1.34	1.11	0.89	0.86	6.5	22.8
	6.08	1.10	0.92	0.74	0.63	6.7	20.5
	6.57	1.10	0.80	0.69	0.58	6.4	21.5
	7.01	0.97	0.88	0.63	0.52	6.6	21.6
	7.47	0.79	0.64	0.57	0.49	5.4	19.7
Marion-ville	5.42	1.53	1.41	1.12	1.06	21.7	104.8
	5.89	1.42	1.28	1.13	1.07	24.8	111.2
	6.47	1.43	1.24	1.00	0.90	22.2	116.0
	7.01	1.24	1.16	0.93	0.81	24.5	118.5
	7.33	1.11	1.00	0.86	0.71	20.4	111.2
Bearbrook	5.26	1.13	0.89	0.81	0.72	14.3	59.9
	5.92	1.14	1.03	0.84	0.72	19.5	71.3
	6.35	0.93	0.92	0.67	0.63	18.3	55.8
	6.95	0.80	0.77	0.60	0.56	16.0	57.4
	7.43	0.71	0.62	0.49	0.42	12.6	39.5
St.Thomas	5.84	1.48	1.15	0.98	0.97	9.8	26.6
	6.46	1.18	1.00	0.86	0.72	8.8	28.7
	7.10	0.90	0.77	0.81	0.65	7.9	28.1
	7.53	1.00	0.67	0.78	0.54	7.1	26.1
Mountain	5.79	0.76	0.78	0.72	0.66	19.5	78.3
	6.34	0.80	0.78	0.64	0.65	19.8	80.9
	7.00	0.72	0.74	0.60	0.63	23.0	78.3
	7.55	0.68	0.65	0.56	0.53	14.3	59.7
Rideau	5.88	0.75	0.61	0.57	0.53	40.6	117.4
	6.15	0.71	0.67	0.52	0.48	44.7	149.7
	6.83	0.67	0.66	0.55	0.53	42.5	157.8
	7.38	0.58	0.60	0.49	0.50	39.7	148.2

*Calculated from Mg and P equivalent values to the plants. The relative rating of the different soils with respect to easily soluble magnesium agrees quite well with the results for exchangeable magnesium in the soils as given in Table 111. The water-soluble magnesium in the St. Thomas soil decreased consistently with increasing pH. The soluble magnesium as determined by either method tended to decline in the samples of Manotick soil at a pH above neutrality. In all other comparisons, both methods showed trends for the soluble magnesium to increase as the pH of the soil was increased to some level, at which point the values tended to decrease with increasing pH. Except for the magnesium in the Marionville and Rideau soils extracted with 0.013N acetic acid, the magnesium determined by either method was lower in the soils limed to a pH of about 7.5 than in the unlimed soils. At a pH of about 7.0, however, the amounts of soluble magnesium were quite similar to those found in the unlimed samples, except for the Marionville and Rideau soils, where each of the rates of lime increased the magnesium values over those obtained without liming. The Marionville and Rideau soils contained considerably more magnesium than the other soils tested.

Truog, Goates, Gerloff, and Berger (1947) reported an appreciable increase in the phosphorus content of peas with increasing supplies of available magnesium. In a study of twenty New Jersey soils, Prince, Toth, and Bear (1948) found the average Mg-P ratio within alfalfa to be approximately

1. In the present investigation, the increasing uptake of phosphorus resulting from increasing rates of liming material containing no magnesium, was associated with decreasing Mg-P ratios. Nevertheless, it is quite possible that addition of magnesium might have further assisted in mobilizing phosphorus into the plant.

D. Relationship of Soil Reaction and Potassium Supplying Power of Soils

1. Effect of Soil pH on Removal of Potassium, Magnesium and Calcium by Alfalfa

In considering the potassium content of the alfalfa, grown in the greenhouse experiment, it seemed advisable to give attention also to the magnesium and calcium contents of the plants. The effects of pH and the corresponding per cent base saturation as established by liming, on the potassium, magnesium, and calcium contents of alfalfa grown with different phosphorus and potassium treatments, are shown by the data in Table XX. The least significant differences between the means reported, based on the error of determination of the cations in the plant ash, were 3.8, 2.4, and 6.8 m.e. for potassium, magnesium and calcium respectively.

The potassium content of the alfalfa varied considerably with the fertilizer treatments, the values for most of the soils being relatively low in the P series and relatively high

TABLE XX

CATION CONTENT OF ALFALFA, GROWN AT DIFFERENT pH LEVELS WITH DIFFERENT FERTILIZER TREATMENTS
(Mean of duplicate determinations on ash of composite samples, expressed on basis of 100 grams of oven-dry material)

Soils	pH	Base Saturation	Fertilizer Treatments											
			Check			P			K			P+K		
			K	Mg	Ca	K	Mg	Ca	K	Mg	Ca	K	Mg	Ca
		%	me	me	me	me	me	me	me	me	me	me	me	me
Mano-tick	5.56	34	39	39	120	18	40	130	67	30	94	35	30	110
	6.08	56	34	33	128	12	34	140	63	22	102	24	24	116
	6.57	70	24	32	143	12	34	142	54	20	114	26	23	125
	7.01	86	17	28	147	11	31	140	47	22	126	28	22	136
	7.47	100	15	26	149	9	29	154	40	18	139	28	23	139
Marion-ville	5.42	60	44	55	87	24	57	84	56	45	79	37	50	82
	5.89	73	34	51	88	13	59	99	55	41	80	31	48	89
	6.47	81	28	53	109	14	55	115	48	41	86	28	43	96
	7.01	90	22	51	117	14	55	122	42	43	101	26	43	107
	7.33	100	17	49	128	17	55	133	37	43	108	24	42	109
Bear-brook	5.26	53	37	45	87	35	44	83	46	34	87	46	36	81
	5.92	69	39	40	103	27	41	111	43	34	96	40	34	88
	6.35	78	31	38	105	23	36	115	43	34	102	33	32	85
	6.95	89	28	37	122	25	34	112	40	33	113	32	32	100
	7.43	100	23	37	136	25	31	112	37	31	117	29	27	100
St. Thomas	5.84	46	53	40	119	24	40	149	71	31	109	46	36	122
	6.46	70	52	33	135	16	36	162	73	27	113	38	26	145
	7.10	90	41	28	146	14	34	177	78	20	111	33	24	151
	7.53	100	30	29	157	12	32	184	64	18	126	33	21	167
Moun-tain	5.79	64	52	35	75	45	39	86	68	32	77	52	33	83
	6.34	76	49	36	83	37	36	91	51	31	81	46	33	83
	7.00	91	34	36	100	28	34	101	42	32	89	36	35	100
	7.55	100	32	36	107	29	35	114	41	31	103	36	31	102
Rideau	5.88	75	70	33	61	72	30	74	78	27	62	69	27	65
	6.15	84	66	32	68	70	29	60	77	29	60	70	26	57
	6.83	88	66	32	74	68	31	75	73	31	67	66	29	74
	7.38	100	68	29	67	63	29	79	69	30	82	70	27	79

in the K series when compared with those in the check or P/K series. Except for the K series of the St. Thomas and the check series of the Rideau soil, the potassium content of the plants in these two series decreased with increasing pH of the soils. In the P and P/K series, the alfalfa grown on the unlimed samples of all soils except Rideau, contained appreciably more potassium than was found in the corresponding limed samples of these series. At the higher pH levels where phosphorus was applied, however, there were several instances where the potassium content of the plants did not decrease further, as the pH of the soil was raised above the neutral point. As illustrated in Figure 6, the occurrence of decreasing values for the potassium content of the plants with increasing pH, was associated in most instances with increase in yield. On the other hand, in the P and P/K series, the relatively constant potassium content of the crop at the higher pH levels as shown in several instances, was associated with relatively constant yield.

It would appear from these results that the occurrence of decreases in the potassium content of alfalfa on limed soils, was perhaps the result of the higher yields obtained following liming. The variation in the potassium content of the alfalfa, associated with the variation in yield of the crop in the different fertilizer series, illustrates the influence of yield on the potassium content of the plants. There were several instances, particularly under conditions

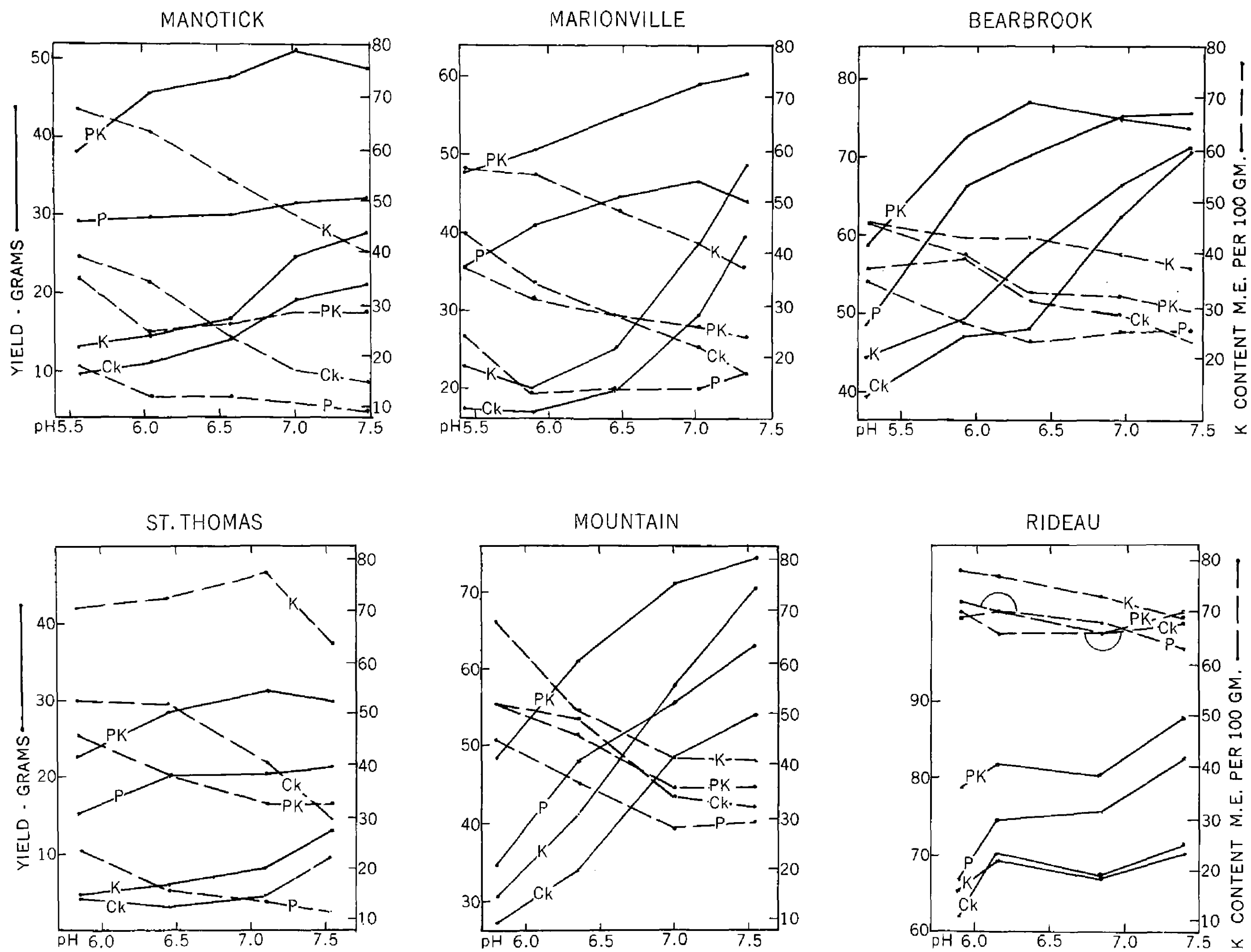

Fig.6 Effect of Soil pH on the Yield and Potassium Content of Alfalfa, Grown at Different pH Levels in Different Fertilizer Series on Six Soils.

of relatively constant yield, where increase in the base saturation of the soil from about 90 per cent to complete saturation by addition of lime, did not appear to have any depressive effect on absorption of potassium by the plants. Recently, York, Bradfield and Peech (1953b) reported that the concentration of potassium in alfalfa decreased slightly with increasing degree of calcium saturation of the soil, but additions of sufficient lime to maintain free calcium carbonate in the soil, resulted in an increase in the potassium content of the crop.

The magnesium content of the alfalfa tended to decrease, particularly with the first increment of lime applied to the Manotick, Marionville, Bearbrook, and St. Thomas soils. Application of potassium, which with few exceptions, increased the yield of the crop, resulted in a decrease in the magnesium content of the plants, as compared with the values obtained in the corresponding series where no potassium was applied. Addition of potassium resulted in a greater decrease in the magnesium content of the plants than occurred with the first increment of lime. In some instances, this may have been the result of a higher yield being obtained with the potassium treatment than with the particular rate of lime. However, it is interesting to note that this trend for potassium to have a greater depressive effect than calcium on the absorption of magnesium by the plants occurred for the Bearbrook and Mountain soils where the yield for the potassium treatment was either similar or less than that for the first increment of lime. In the P and P/K series, the magnesium content of the plants did not tend to decrease below that occurring in the absence of applied phosphorus, despite the higher yields obtained in the series where phosphorus was applied. It would appear that either the magnesium content of the plants was not influenced by yield, or that the phosphorus fertilizer containing gypsum tended to assist in mobilizing magnesium into the plants.

The calcium content of the alfalfa increased in most instances with increasing percentages of base saturation of the soils. The higher concentration of calcium in the plants in the P and P/K series, as compared with that in the appropriate series without phosphorus, is probably due to the gypsum included in the phosphorus fertilizer. With all soils except Rideau, application of potassium resulted in lower values for the calcium content of the alfalfa than were obtained in the corresponding series without applied potassium.

The influence of lime and the fertilizer treatments on the Ca-K, Mg-K, and Ca-Mg ratios in the alfalfa, is shown by the data in Table XXl. The Ca-K and Ca-Mg ratios in the plants increased in most instances with increasing degree of base saturation of the soils. The increasing Mg-K ratios with increasing degrees of base saturation of most of the soils, where no fertilizer was applied, indicate that the absorption of potassium by the plants was depressed more than that of magnesium as a result of liming. In the absence of applied potassium, the Ca-K ratios were relatively high for the alfalfa grown on the Manotick, Marionville and St. Thomas soils. There was no tendency for yields of alfalfa on any of the soils to decrease with any of the treatments, regardless of the resulting ratios of cations in the plants. In a study of different Ca-K ratios in prepared soils, Hunter, Toth and Bear (1943) found that the yield of alfalfa decreased when the Ca-K ratio in the plants exceeded 4:1.

The different fertilizer treatments had little effect on the Ca-Mg ratios in the alfalfa. On the other hand, the Ca-K ratios tended to increase with application of phosphorus, and to decrease with application of potassium. In addition to supplying potassium, the latter treatment decreased the calcium content of the plants. In the present investigation, where applied potassium increased the yields, it is impossible to separate the effect of the higher yield from the direct effect of the potassium ion on the absorption of calcium. Other investigators, including Chu and Turk (1949), and York, Bradfield and Peech (1953b) have shown that potassium represses the absorption of calcium by plants.

Although there was considerable variation in the cation composition of the alfalfa, the data in Table XXll show that the sum of the cations in the plants was essentially constant for the different treatments applied to each of the soils.

TABLE XX1

CATION-EQUIVALENT RATIOS IN ALFALFA, GROWN AT DIFFERENT pH LEVELS, WITH DIFFERENT FERTILIZER TREATMENTS

Soils	pH	Base Saturation %	Fertilizer Treatments: Check Ca/K	Check Mg/K	Check Ca/Mg	P Ca/K	P Mg/K	P Ca/Mg	K Ca/K	K Mg/K	K Ca/Mg	P+K Ca/K	P+K Mg/K	P+K Ca/Mg
Manotick	5.56	34	3.1	1.0	3.1	7.2	2.2	3.3	1.4	0.5	3.1	3.1	0.9	3.7
	6.08	56	3.9	1.0	3.9	11.7	2.8	4.1	1.6	0.4	4.6	4.8	1.0	4.8
	6.57	70	6.0	1.3	4.5	11.8	2.8	4.2	2.1	0.4	5.7	4.8	0.9	5.4
	7.01	86	8.7	1.7	5.3	12.7	2.8	4.5	2.7	0.5	5.7	4.9	0.8	6.2
	7.47	100	9.9	1.7	5.7	17.1	3.2	5.3	3.5	0.5	7.7	5.0	0.8	6.0
Marion-ville	5.42	60	2.0	1.3	1.6	3.5	2.4	1.5	1.4	0.8	1.8	2.2	1.4	1.6
	5.89	73	2.6	1.5	1.7	7.6	4.5	1.7	1.5	0.8	2.0	2.9	1.6	1.9
	6.47	81	3.9	1.9	2.1	8.2	3.9	2.1	1.8	0.9	2.1	3.4	1.5	2.2
	7.01	90	5.3	2.3	2.3	8.7	3.9	2.2	2.4	1.0	2.4	4.1	1.7	2.5
	7.33	100	7.5	2.9	2.6	7.8	3.2	2.4	2.9	1.2	2.5	4.5	1.8	2.6
Bear-brook	5.26	53	2.4	1.2	1.9	2.4	1.3	1.9	1.9	0.7	2.6	1.8	0.8	2.3
	5.92	69	2.6	1.0	2.6	4.1	1.5	2.7	2.2	0.8	2.8	2.2	0.9	2.6
	6.35	78	3.4	1.2	2.8	5.0	1.6	3.2	2.4	0.8	3.0	2.6	1.0	2.7
	6.95	89	4.4	1.3	3.3	4.5	1.4	3.3	2.8	0.8	3.4	3.1	1.0	3.1
	7.43	100	5.9	1.6	3.7	4.5	1.2	3.6	3.2	0.8	3.8	3.5	0.9	3.7

TABLE XXl (continued)

Soils	pH	Base Saturation %	Check Ca/K	Check Mg/K	Check Ca/Mg	P Ca/K	P Mg/K	P Ca/Mg	K Ca/K	K Mg/K	K Ca/Mg	P+K Ca/K	P+K Mg/K	P+K Ca/Mg
St.Thomas	5.84	46	2.3	0.8	3.0	6.2	1.7	3.7	1.5	0.4	3.5	2.7	0.8	3.4
	6.46	70	2.6	0.6	4.1	10.1	2.3	4.5	1.6	0.4	4.2	3.8	0.7	5.6
	7.10	90	3.6	0.7	5.2	12.6	2.4	5.2	1.4	0.3	5.6	4.6	0.7	6.3
	7.53	100	5.4	1.0	5.4	15.3	2.7	5.8	2.0	0.3	7.0	5.1	0.6	8.0
Mountain	5.79	64	1.4	0.7	2.1	1.9	0.9	2.2	1.1	0.5	2.4	1.6	0.6	2.5
	6.34	76	1.7	0.7	2.3	2.5	1.0	2.5	1.6	0.6	2.6	1.8	0.7	2.5
	7.00	91	2.9	1.1	2.8	3.6	1.2	3.0	2.1	0.8	2.8	2.9	1.0	2.9
	7.55	100	3.3	1.1	3.0	3.9	1.2	3.3	2.5	0.8	3.3	2.8	0.9	3.3
Rideau	5.88	75	0.9	0.5	1.9	1.0	0.4	2.5	0.8	0.4	2.3	0.9	0.4	2.4
	6.15	84	1.0	0.5	2.1	0.9	0.4	2.1	0.8	0.4	2.1	0.8	0.4	2.2
	6.83	88	1.1	0.5	2.3	1.1	0.5	2.4	0.9	0.4	2.2	1.1	0.4	2.6
	7.38	100	1.0	0.4	2.3	1.3	0.5	2.7	1.2	0.4	2.7	1.1	0.4	2.9

TABLE XX11

SUM OF POTASSIUM, MAGNESIUM, AND CALCIUM CONTENTS OF ALFALFA, GROWN WITH DIFFERENT TREATMENTS
(Calculated from data in Table XX, and based on 100 grams of oven-dry material)

Soils	pH	Base Saturation	Fertilizer Treatments Check	P	K	P+K
		%	m.e.	m.e.	m.e.	m.e.
Manotick	5.56	34	198	188	191	175
	6.08	56	1195	186	187	164
	6.57	70	199	188	188	174
	7.01	86	192	182	195	186
	7.47	100	190	192	197	190
Marion-ville	5.42	60	186	165	180	169
	5.89	73	173	171	176	168
	6.47	81	190	184	175	167
	7.01	90	190	191	186	176
	7.33	100	194	205	188	175
Bearbrook	5.26	53	169	162	167	163
	5.92	69	182	179	173	162
	6.35	78	174	174	179	150
	6.95	89	187	171	186	164
	7.43	100	196	168	185	156
St.Thomas	5.84	46	212	213	211	204
	6.46	70	220	214	213	209
	7.10	90	215	225	209	208
	7.53	100	216	228	208	221
Mountain	5.79	64	162	170	177	168
	6.34	76	168	164	163	162
	7.00	91	170	163	163	171
	7.55	100	175	178	175	169
Rideau	5.88	75	164	176	167	161
	6.15	84	166	159	166	153
	6.83	88	172	174	171	169
	7.38	100	164	171	181	176

There was a trend for the values to be slightly lower in the P≠K series than in the other fertilizer series. The values for the sum of the cations in the crop were somewhat higher for the St. Thomas than for the other soils. Among others, Wallace, Toth, and Bear (1948), and York, Bradfield and Peech (1954), have reported similar results with respect to the constancy of the sum of the cations in alfalfa.

2. Effect of Soil pH and Per Cent Base Saturation on Water-soluble and Exchangeable Potassium in Soils

The data for water-soluble and exchangeable potassium in the soils limed to different pH levels prior to seeding alfalfa, are presented in Table XX111.

The results show that at least some of the liming treatments significantly reduced the water-soluble potassium in all of the soils, and the exchangeable potassium in the Manotick, Marionville, St. Thomas and Mountain soils. The magnitude of the differences was small, but in a few instances the different rates of lime showed a rather consistent pattern. For example, water-soluble potassium tended to decrease with increasing degree of base saturation of the Marionville soil. The decreases in water-soluble and in exchangeable potassium as a result of liming the St. Thomas soil were each constant for the different rates of lime. In the Mountain soil, there were decreases in the water-soluble and exchangeable potassium

TABLE XX111

EFFECT OF pH AND PER CENT BASE SATURATION ON WATER-SOLUBLE AND EXCHANGEABLE POTASSIUM IN SOILS PRIOR TO SEEDING ALFALFA
(Mean of duplicate determinations as K per 100 grams of air-dry soil)

Soils	pH	Base Saturation	Water-soluble Potassium	Exchangeable Potassium	L.S.D.* (P.05)
		%	m.e.	m.e.	m.e.
Manotick	5.56	34	0.026	0.119	
	6.08	56	0.019	0.106	
	6.57	70	0.021	0.105	
	7.01	86	0.019	0.108	
	7.47	100	0.022	0.106	0.007
Marion-ville	5.42	60	0.018	0.242	
	5.89	73	0.017	0.238	
	6.47	81	0.017	0.223	
	7.01	90	0.015	0.217	
	7.33	100	0.013	0.223	0.012
Bearbrook	5.26	53	0.026	0.296	
	5.92	69	0.020	0.288	
	6.35	78	0.023	0.304	
	6.95	89	0.019	0.292	
	7.43	100	0.021	0.287	0.015
St.Thomas	5.84	46	0.028	0.126	
	6.46	70	0.021	0.109	
	7.10	90	0.020	0.109	
	7.53	100	0.020	0.109	0.014
Mountain	5.79	64	0.038	0.289	
	6.34	76	0.035	0.283	
	7.00	91	0.035	0.268	
	7.55	100	0.037	0.302	0.012
Rideau	5.88	75	0.039	0.561	
	6.15	84	0.041	0.561	
	6.83	88	0.037	0.558	
	7.38	100	0.037	0.564	0.033

* Based on laboratory error for exchangeable K including samples taken after harvest; the L.S.D. for water-soluble K = 0.002 m.e.

as a result of liming up to 90 per cent base saturation, at which point, the respective values increased to approach that for water-soluble and to exceed that for exchangeable potassium in the unlimed samples.

The data for exchangeable potassium in the samples obtained after harvest of alfalfa, as influenced by liming and fertilizer treatments as well as by the removal of potassium by the crops, are presented in Table XX1V. The results show that lime tended to decrease the exchangeable potassium in at least some of the fertilizer series of all soils except Rideau. The effect of lime on exchangeable potassium was most apparent in the results for the K series, where the values decreased with successive increments of lime applied to the Manotick, St. Thomas, and Mountain soils. Exchangeable potassium in the K series also decreased in the Marionville and Bearbrook soils when the base saturation was raised to about 80 per cent or above. In the P/K series, the exchangeable potassium decreased significantly in the St. Thomas and Mountain soils as the base saturation was increased to about 90 per cent, and there were further decreases in the completely base saturated samples. Where no potassium was applied, there were significant decreases in the values for exchangeable potassium in the Marionville, St. Thomas and Mountain soils as the degree of base saturation of these soils was increased to about 90 per cent, and the values decreased further in the completely base saturated samples.

TABLE XXlV

EXCHANGEABLE POTASSIUM AFTER HARVEST AND AMOUNTS OF POTASSIUM REMOVED BY CROP
(Mean of duplicate determinations of exchangeable K as m.e. per 100 grams of air-dry soil; mgm. of K removed per pot as calculated from Tables V and XX)

Soils	pH	Base Satura-tion %	Exchangeable K in Different Fertilizer Series					Amounts of K Removed in Different Fertilizer Series			
			Check	P	K	P+K	L.S.D.*	Check	P	K	P+K
Mano-tick	5.56	34	0.044	0.041	0.116	0.046		133	186	315	478
	6.08	56	0.050	0.047	0.090	0.051		133	122	325	390
	6.57	70	0.042	0.041	0.075	0.050		122	124	355	447
	7.01	86	0.046	0.046	0.070	0.050		117	125	410	506
	7.47	100	0.044	0.039	0.059	0.043		115	106	428	488
							0.007				
Marion-ville	5.42	60	0.188	0.173	0.223	0.181		270	302	465	628
	5.89	73	0.183	0.171	0.223	0.200		201	190	397	556
	6.47	81	0.188	0.165	0.196	0.190		198	212	435	537
	7.01	90	0.166	0.158	0.183	0.177		232	232	571	556
	7.33	100	0.148	0.150	0.167	0.175		250	259	642	522
							0.012				
Bear-brook	5.26	53	0.162	0.156	0.191	0.162		513	605	724	955
	5.92	69	0.177	0.169	0.196	0.169		655	633	762	1040
	6.35	78	0.181	0.179	0.187	0.173		524	588	880	897
	6.95	89	0.160	0.168	0.181	0.162		621	662	951	869
	7.43	100	0.154	0.148	0.167	0.156		577	676	938	760
							0.015				

*At (P.05), and based on laboratory error including that for samples before seeding

TABLE XXIV (continued)

Soils	pH	Base Saturation %	Exchangeable K in Different Fertilizer Series: Check	P	K	P+K	L.S.D.*	Amounts of K Removed in Different Fertilizer Series: Check	P	K	P+K
St.Thomas	5.84	46	0.084	0.054	0.209	0.083		78	128	112	368
	6.46	70	0.077	0.048	0.170	0.074		58	114	156	377
	7.10	90	0.065	0.044	0.168	0.068		65	99	225	370
	7.53	100	0.046	0.022	0.099	0.049		100	90	288	345
							0.014				
Mountain	5.79	64	0.114	0.121	0.177	0.135		500	551	732	880
	6.34	76	0.116	0.117	0.164	0.139		598	630	751	997
	7.00	91	0.085	0.104	0.123	0.119		582	546	869	903
	7.55	100	0.081	0.083	0.116	0.112		622	649	1016	960
							0.012				
Rideau	5.88	75	0.366	0.363	0.388	0.378		1550	1701	1817	1930
	6.15	84	0.363	0.346	0.379	0.375		1657	1891	1893	2054
	6.83	88	0.363	0.391	0.398	0.375		1583	1834	1762	1903
	7.38	100	0.365	0.353	0.395	0.385		1751	1866	1730	2188
							0.033				

*At (P.05), and based on laboratory error including that for samples before seeding

The direct effect of lime on the exchangeable potassium in the samples obtained after harvest of the crop is somewhat obscured by the removal of potassium by the plants. It is impossible to relate samll differences in exchangeable potassium in the soils to the amounts of potassium removed by the crop, because of the errors involved as well as the fact that the potassium contained in the roots of the alfalfa was not determined. In the K series the decreases in exchangeable potassium with increase in rates of liming were accompanied by increases in the amounts of potassium removed by the plants. The lower values for exchangeable potassium in the completely base saturated samples of Marionville and Mountain soils where no potassium was applied, were associated with relatively high values for the amounts of potassium removed from the soils limed to about 90 per cent base saturation. There were numerous instances, however, where the values for exchangeable potassium were not related to the amounts of potassium removed by the crop. For example, decreases in exchangeable potassium were associated with decreases in uptake of potassium by the plants as a result of increasing rates of lime in the P series of the St. Thomas soil. It would appear that liming effected some decrease in the amount of exchangeable potassium in some of the samples obtained after harvest that could not be attributed to removal by the crop.

With few exceptions, the values for exchangeable potassium after harvest showed appreciable decreases from those obtained for the samples taken prior to seeding the crop. In this connection it is interesting to note that cropping produced a marked decline in the exchangeable potassium in the Rideau soil although lime and fertilizer treatments had no effect on the exchangeable potassium in this soil.

York, Bradfield and Peech (1953a) found that additions of lime up to 78 per cent base saturation resulted in a reduction of both water-soluble and exchangeable potassium in a silt loam soil. In the presence of excess calcium carbonate, exchangeable potassium was further reduced whereas water-soluble potassium was increased. The results of the present study indicate that liming slightly reduced the water-soluble potassium in soils varying from loamy sand to clay in texture, and exchangeable potassium in the lighter textured soils. In most instances, these decreases in water-soluble and exchangeable potassium as a result of liming, occurred over a wide range including complete saturation. At complete saturation carbonate occurred only in traces. It would appear that at least a slight reduction in available potassium in the soils following liming, contributed along with higher yields to the decreases in the potassium content of the alfalfa, which frequently occurred as the pH values of the soils were increased by increments of lime to slightly above the neutral point.

VI. SUMMARY

The effects of different pH levels as established by liming on the availability of phosphorus and potassium in surface samples of six soils of Eastern Ontario, were studied in pot tests as well as in the laboratory.

The soils varied in texture from loamy sand to clay, in organic matter from 3.65 to 5.04 per cent, in pH from 5.45 to 6.00, and in exchange capacity from 8.46 to 17.89 milliequivalents per 100 grams of soil.

To three of the soils with pH values of approximately 5.5, different rates of calcium hydroxide were added to raise the pH of the soils in pots to approximately 6.0, 6.5, 7.0 and 7.5. The other three soils with initial pH values of about 6.0, were limed to approximately 6.5, 7.0 and 7.5 pH units.

After the desired pH levels were established, alfalfa was grown in the unlimed and limed soils without fertilizer and with phosphorus and potassium treatments applied singly and in combination.

Lime, phosphorus and potassium treatments each significantly increased the yield of alfalfa on each of the soils, whereas the differences in yield between rates of lime were significant for all but one of the soils. The interaction between rates of lime and phosphorus with respect to yield, were significant

for all soils except the heavy-textured Rideau. The only significant interaction between lime and potassium treatments occurred for the light-textured Manotick and St. Thomas soils. In all soils except Rideau, the yield of alfalfa where no phosphorus was applied, was significantly higher in most instances at a pH of about 7.5 than at any lower pH level. In the presence of applied phosphorus, however, there was evidence that the optimum pH for alfalfa was reached at about pH 6.5 to 7.0, above which no further increases in yield were obtained. From the yield data it appeared that liming had a beneficial effect on the soil phosphorus supply for alfalfa. On four of the soils limed to a pH of about 7.5, the yields obtained without application of phosphorus were equal to or higher than those recorded for the unlimed samples receiving phosphorus fertilizer.

The increasing phosphorus content of the alfalfa associated with either increasing or relatively constant yields as the pH of four of the soils in particular was raised above neutrality, provided evidence that a pH of about 7.5 was more favorable than any lower pH level investigated, for supplying either native or applied phosphorus to the plants. With few exceptions, the results indicated a pronounced increase in the uptake of phosphorus with increasing pH level.

The amounts of phosphorus extracted by the Truog method from the soils sampled prior to seeding the crop, increased with increasing pH of most of the soils, the highest values occurring at a pH of about 7.0 or 7.5. The results obtained by this method for soil samples taken after harvest of the crop, indicated that liming the soils to at least the neutral point, increased the availability of native and applied phosphorus. The amounts of phosphorus extracted by the methods of Bray were not appreciably affected by the application of lime. There were trends, however, for the adsorbed plus acid-soluble forms to decrease slightly with increases in the pH of the Rideau soil and for the adsorbed form to increase slightly with increasing pH of the Marionville, Bearbrook and Rideau soils. The amounts of phosphorus extracted by sodium bicarbonate prior to seeding, declined as a result of the lower rates of lime, but at a pH of about 7.0 or more particularly at about 7.5, the phosphorus values were higher than those obtained in the unlimed samples for all but the light-textured Manotick and St. Thomas soils.

The increasing uptake of phosphorus by the alfalfa as a result of liming was associated with decreasing Mg-P ratios in the plants. In all but the light-textured Manotick and St. Thomas soils, the water-soluble magnesium and that extracted with 0.013N acetic acid, tended to increase as the pH of the soils was raised to some extent, at which points the values decreased with increasing pH.

Where no phosphorus was applied, the potassium content of the plants decreased in most instances with increasing yield associated with increasing pH of the soils. On the other hand, with applied phosphorus there were several instances at the higher pH levels, where the potassium content of the plants was relatively constant in association with relatively constant yield. The absorption of potassium by alfalfa was depressed more than that of magnesium as a result of liming, as shown by increasing Mg-K ratios with increasing degrees of base saturation of most of the soils. Although there was considerable variation in the cation composition of the alfalfa, the sum of the cations in the plants was essentially constant for the different treatments applied to each of the soils.

Water-soluble potassium decreased slightly in all of the soils with the possible exception of Rideau, and exchangeable potassium decreased slightly in four of the soils as a result of at least some of the lime treatments. In the Mountain soil, however, both water-soluble and exchangeable potassium increased in the completely base saturated samples as compared with the values obtained for lower rates of liming. From these results and from those obtained for the samples taken after harvest it would appear that certain decreases reported for the potassium content of alfalfa following liming, were partly the result of a slight reduction in the available potassium in the soil, although the effect of increasing yield with liming was probably more important.

The results of this investigation indicate that liming up to or slightly above the neutral point, may be expected to have a favorable influence on the availability of native and applied phosphorus, without greatly reducing the available potassium in the soil.

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