A STUDY OF THE AVAILABILITY OF NATIVE AND APPLIED PHOSPHORUS TO ONIONS AND POTATOES GROWN ON A HOUGHTON MUCK

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ABSTRACT

A STUDY OF THE AVAILABILITY OF NATIVE AND APPLIED PHOSPHORUS TO ONIONS AND POTATOES GROWN ON A HOUGHTON MUCK

by Lo-Tung Wang

Field and laboratory investigations were carried out to determine the response of onions and potatoes to native and applied fertilizer phosphorus, and to evaluate the importance of organic phosphorus as a source of available inorganic phosphorus to plants grown on a newly reclaimed Houghton muck.

The response of potatoes to applied fertilizer phosphorus on a virgin Houghton muck, was less than that of onions. The depression in potato yields resulting from high rates of applied fertilizer P may possibly be associated with a decrease in plant uptake of zinc.

The Baule units of soil and fertilizer P were obtained for onions and potatoes according to the following equation:

$$\log (A-Y) = \log A - c_1 b - cx$$

where, A = the maximum yield of onions and/or potatoes; Y = the yield where no P is applied but other nutrients are present in adequate amounts; c_1 = proportionality constant; b = the amount of soil P present as determined by the Bray P_1

soil test; c = the efficiency factor of the method of applying the fertilizer; and x = the quantity of fertilizer, of the form of nutrient b, that need be added for a desired percentage yield. In general, the Baule units of soil and fertilizer P for potatoes and onions grown on a virgin Houghton muck were less than the cultivated muck soils.

An increase in the total phosphorus content of all soils was obtained with the application of fertilizer phosphorus; however, the inorganic phosphorus content of the virgin soil was less than the cultivated and fertilized soils.

The percent organic phosphorus decreased with increasing levels of fertilizer phosphorus, being highest on the virgin soil (75 percent) and lowest (50 percent) on the soils receiving 88 pounds of phosphorus per acre for a 3-year period.

Soil incubation studies indicated that virgin muck may be a source of phosphorus for plant growth. There was no evidence to indicate, however, that the release of inorganic phosphorus was dependent upon the amount of applied phosphorus.

Water-extractable and .05 N HCl-extractable P^{32} indicated that cultivated muck soils retained more phosphorus than the virgin organic soil.

The data suggest that the efficiency of fertilizer phosphorus in muck soils would differ depending upon the extent of cultivation and phosphorus treatment. Accordingly, the response of crops to fertilizer phosphorus would also change.

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INTRODUCTION

A hungering world is facing an imminent shortage of food and a surplus of people. The food-people situation is alarming scientists and economists. Each year a new nation is born--the current birth rate adds nearly 70 million people to the world each year. And the numbers are increasing. More food must be produced at an alarming rate if the needs are to be met.

Organic soils constitute important potential soil reserves for the nation and the world. Of the 4-1/2 to 5 million acres of organic soils in Michigan, representing 1 acre in 8, less than 5 percent is farmed. However, they represent an important economic part of the agricultural production of the state and will play an even greater role in world food production.

A large percentage of organic soils in the United States was formed in potholes, lakes and river beds following glacial action. Glacial action is the most important causal agent in the development of organic soils in Michigan and other northern states (16).

It is important that we have a knowledge of the fertility problems associated with these soils if good quality food is to be produced with adequate economic returns. The fertilization of new or reclaimed organic soils presents management problems different from those that have been cultivated and cropped for many years.

Since organic soils are formed from plant materials, it is not surprising that from 30 to 85 percent of the total phosphorus in virgin organic soils is in the organic form (85a). Five forms of organic phosphorus--phospholipids, nucleic acid, inositol phosphates, "metabolic" phosphates and phosphoproteins- have been suggested as components of organic soils. Of course, organic phosphorus has to be mineralized before it can be utilized by plants.

This investigation was initiated and carried out at the Michigan State University Muck Experimental Farm in Clinton County to correlate the response of onions and potatoes to native and applied fertilizer phosphorus, and to evaluate the importance of organic phosphorus as a source of available inorganic phosphorus to plants grown on newly reclaimed mucks.

LITERATURE REVIEW

Brief Review of Composition of Organic Soils

Organic soil deposits spread over a large area of the United States, but only a small percentage is farmed. In Michigan, 4.5 millions acres of land are classified as organic soils which include the soil series of Carlisle, Rifle, Lupton, Markey, Rollin, Carbondale, Houghton, Linwood, Ogden, Palms, Adrian, Willette Cathro, Lake Marsh, Tawas, Kerston, Greenwool, Dawson, Loxley, and Spalding. These organic soils contain at least 20 to 30 percent organic matter but differ in various properties such as texture, color, botanical composition, etc. (16, 24).

Houghton muck, on which this research was carried out, is black to dark brown in color, granular and very friable in structure. It is composed of fibrous plant remains which consist of grasses, sedges, reeds, and other non-woody water tolerant plants over a depth of 42 inches. Its pH is about 6.0. The soil is poorly drained due to its low elevation, and hence its permeability is moderate (86).

Virgin Houghton muck, prior to drainage, has a grass-type vegetation. After the land has been drained, however, a forest-type vegetation may predominate. Before a virgin muck can be cultivated, the vegetation must be removed and put in pasture for several years.

A virgin muck is rarely considered a fertile soil. A newly reclaimed muck usually receives very high rates of fertilizers in order to obtain good yields. Harmer (25) reported that in the beginning, applications of potassium and phosphorus for most crops were thought to be sufficient for satisfactory production; but later on, it was known that under certain conditions, nitrogen as well as copper, manganese, boron, zinc, molybdenum and sodium were also important for high crop yields. Subsequent investigations showed that deficiencies of the micronutrients could occur in many cases (52). Roe (66) indicated that the fertilization problem of peat and muck soils was very complex. He further suggested that fertilizer requirements of these soils were dependent on lime content.

Level of Total Phosphorus and Organic Phosphorus in Organic Soils

Considerable work has been done to evaluate the P status of soils. Early investigations were carried out primarily on mineral soils. Schollenberger (70) working with Ohio soils, reported that the total P content of virgin soils was considerably higher than the corresponding value for cultivated soils, and only a small percentage was attributed to organic P. Auten (2), Pearson and Simonson (62), examined Iowa soils with respect to organic P and found that the organic P content decreased with depth. Recently, Kaila (37) analyzed hundreds of Finnish soils with her modified method (36) and reported that the organic P content ranged from 100 ppm to 940 ppm corresponding to 17 and 68 percent, respectively, of the total P content of these soils. She also pointed out that the total P content of virgin mineral soils was markedly lower than that of the corresponding cultivated soils.

As far as the P contents of organic soils are concerned, systematic investigation did not start until recently possibly due, in part, to the difficulties encountered in the chemical analysis. Paul (60), investigated the P status of virgin and cropped peat soils of British Guiana and found that the total P content of the virgin soil was higher than that of the cultivated soil; and after cropping, the yield obtained on the virgin peat was generally higher than that obtained on the cultivated soil. It appeared that virgin peat soils possessed greater available P than the cultivated soils. Additional evidence was obtained from Kaila's reports. She investigated 217 samples of virgin peat soils in Finland (34). The results showed that the total P content varied from 190 ppm to 1180 ppm between samples in the same group, it was as high as 2050 ppm in another peat. However, a larger part of P in the peats investigated occurred in the organic form. Her data showed that the organic P content varied from 57 to 93 percent of the total P content. These data indicated that the organic form of P predominated in the virgin peats studied. Similar results were reported by McCall et al (54). Kaila (33) als

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also pointed out that the percentage of organic P increased with depth amounting to about 70 percent of the total P in the surface layer, and approximately 80 percent at a depth of 50 cm. But whether the total P also changed with depth was not mentioned.

Major Forms of Organic and Inorganic Phosphorus in Soils and Their Availability

Three organic phosphorus compounds--phospholipids, nucleic acids and phytin, were ascertained to be present in soils. Schreiner (71) made a general sketch of the components of organic P. Later work was carried on to isolate these components from soil and to estimate their amounts (20, 88, 89). Other researchers studied the reaction of organic P compounds with soil contents and their subsequent derivatives. Dyer and Wrenshall (21) pointed out that phytin was likely to accumulate in soil, especially in acid soil. It combined with sesquioxides and became resistant to enzymatic hydrolysis. They also believed that nucleic acids released from microbial bodies were easily decomposed and were the main source of inorganic P. Jackman and Black (31) further indicated that Al and Fe could precipitate with inositol at a low pH. So far as we know, it could be true that a part of the organic P can supply P for plant growth. Several previous investigations have shown that either native organic P or incorporated organic P can be utilized by crops (4, 6, 35, 63, 88).

Pierre and Parker (63) first proposed that crops planted in soils with a high total P content had less response to phosphate fertilization. The total P represented the sum of the organic and inorganic soil P. But, they were unable to distinguish between organic and inorganic P. Bertramson and Stephenson (4) compared the efficiency of organic P compounds and water soluble superphosphate and found that the latter was in general more available than the former, whereas lecithin or nucleic acids were better suppliers of P than the other organic P compounds studied. They suggested that relative efficiency of organic P was correlated with the simplicity of molecular structure and ease of decomposition.

Bower (6) obtained the same conclusion as Jackman and Black (31) that phytin was least available in acid soil due to precipitation with Fe and Al, but he pointed out, on the other hand, that phytin derivatives were more available than phytin per se. The availability of organic P was based on the fact that the Iowa soil produced high yields with a small amount of phosphate fertilizer, far less than the recommended amount as determined by soil test.

Based on the finding that the rate of mineralization of organic P was dependent on temperature (22, 79), Eid et al (22) assumed that organic P would be more available at higher temperature, and they suggested that a portion of available organic P should be included in the soil test. Kaila (37a) has shown that virgin peat soils could supply a fairly large amount of P to the first cropping in a pot experiment, but larger amounts of P were obtained from soils with the highest content of inorganic P. Nonetheless, it was hard to stress the importance of organic P in this case.

Inorganic forms of P were present mainly as Fe, Al and Ca phosphates. These compounds included monocalcium phosphate, monophosphate monohydrate, dicalcium phosphate, dicalcium phosphate dihydrate, calcium octaphosphate, apatite, hydroxy apatite, variscite and strengite. According to Stelly and Pierre (72), fluorapatite was predominent in the soil. A fractionation method of the three major forms was developed by Chang and Jackson (12). In fact, the relative amounts of these compounds will change from time to time due to environmental influences such as pH, activities of Ca, Al and Fe ions in soil solution and solubility products of the various phosphates (13, 43, 45, 50, 58). The availability of these compounds essentially depends upon the activities of orthophosphates dissociated from these phosphates, since the orthophosphate ions are generally considered readily available to the plant.

Hsu and Jackson (29) pointed out that in a calcareous soil, the variation of total P was much less than the Ca phosphate fraction, and that the leaching loss and plant uptake were less significant than Ca phosphates transformations in soil. A very thorough understanding of phosphate transformations in soil has recently been achieved. Hsu also reported that the Al and Fe phosphates had approximately the same solubility as Ca phosphate between pH 6.0 and 7.0, depending upon the magnitude of cation activities from various solid phases such as gibbsite, alumino-silicates, hydrous Fe oxides, Ca carbonates, exchangeable Ca, and other soluble Ca phosphates, and that they became more stable above pH 7.0. Generally, Ca phosphate is more soluble at lower pH, whereas Fe and Al phosphates are more soluble after the pH is raised to 6.0 or higher.

Aluminum and Fe phosphates could be dissolved to a certain extent before they became occluded by newly formed Fe oxides (12). Haseman, Lehr and Smith (26) classified the products of Fe and Al phosphates into nine groups. According to Taylor, Gurney and Lindsay (78), these Fe phosphates were considered more or less available to plants.

The phosphate reaction products have been widely studied. Although dicalcium phosphate dihydrate was the major product of applied soluble monocalcium phosphate, various forms of Ca compounds were produced in the soil solution under the influence of pH and Ca activity. To indicate the equilibrium among various phosphate compounds, certain solubility diagrams such as phosphate potential (1, 87), and solubility isotherm (8, 9, 43, 44, 56) were established. Lindsay and Stephenson (46, 47, 48, 49) obtained a metastable triple point wherein monocalcium phosphate solution was in equilibrium with newly formed dicalcium phosphate dihydrate and undissolved monocalcium phosphate, by means of dissolving monocalcium phosphate in water. On the other hand, they sampled wet monocalcium phosphate after it was band applied to soil and was moistened by the moisture in the vicinity of the band, and found that the composition of the sample was very close to that of the above-mentioned metastable triple point solution. According to their point of view, the metastable triple state was dynamic; phosphate gradually moved out and precipitated with Fe, Al and Mn in the order Fe $>$ Al $>$ Mn.

Immobilization and Mineralization of Phosphorus

Immobilization and mineralization are among the major processes occurring in soil wherein soil P is transformed from inorganic form to organic form, or vice versa. Nevertheless, these phenomena are mainly attributed to the biological activities, of which plants and micro-organisms play a major role. There is no doubt that micro-organisms are the mainspring of these transformations, and therefore, in this regard, microbial activities in soils have been studied for many years in an attempt to understand the relationship between their activities and the transformation of soil P.

Investigations were undertaken to establish constant C/P and N/P ratios in the soil, assuming that these ratios would shed considerable light on the understanding of microbial immobilization and mineralization of P. Certain tentative constants as C/P = 100, N/P = 10 were proposed after a broad investigation on various soils (35, 37, 61, 62, 70,82). The C/P and N/P ratios in microorganisms were also studied by a number of researchers (3, 35), and it was found, in general, that the P content of soil microorganisms was higher than that of the plant. Incubation studies were widely adopted by many researchers to explore this phenomenon (10, 11, 53, 59, 61, 81, 83). Chang (10, 11) conducted several incubation experiments to study the transformation of P during the decomposition of plant material obtained from young and mature tissues. The results showed that organic P was synthesized at first, and then was mineralized. Pearson et al (61) reported that nucleic acid, phytin and manure when applied to soil would decompose and was likely followed by mineralization. Thompson and Black (79), studying the effect of temperature on mineralization, found that the amount of P mineralized increased rapidly with an increase in temperature up to 150^{o}C. In other words, higher incubation temperature benefited release of organic P. Subsequent work (80) indicated that the quantity of organic P mineralized in virgin soil was more than that mineralized in cultivated soil. Based on the results of previous work, Kaila (35) then postulated that biological immobilization and mineralization during decomposition of organic matter seemed to be analogous to those of N. Working with muck soil, McCall et al (54) reported that mineralization of organic P was increased by means of applying large amounts of soluble inorganic phosphate and incubating for a period of four months. It was also mentioned that besides microbial activities, the action of certain soil catalysts could be a driving force of transformation from organic P to inorganic P (5, 64, 67, 68, 77).

Fixation and Dissolution of Phosphorus and the Role of Organic Matter in Soil

When soluble phosphates are applied to soils, most of the applied phosphate will be fixed into insoluble forms due to many existing factors in the soil and are rendered unavailable to plants. The phosphate ion remaining in soil solution may be as low as 2 to 10 parts per million. The so-called phosphate fixation probably results from three mechanisms, that is, chemical precipitation, physiochemical adsorption, and biological absorption. The third mechanism is designated as immobilization.

In acid soils, the soluble phosphates are likely to react with certain metal ions such as Al, Fe and Mn, and the resulting compounds may be precipitated or adsorbed on the surface of clay particles which contains a great deal of Fe and Al oxides, or exchangeable Al (15, 26, 31, 38). It was also reported that silicate-clays, which contain larger amounts of hydroxyl groups, will fix a portion of phosphate by means of substitution of phosphate ions for hydroxyl groups on the clay surface, or forming a clay-Ca-phosphate complex linkage when saturated with Ca (84). A completely different mechanism has been proposed for alkaline soils. As the pH increases to 7.0, the activity of Ca increases rapidly, and large amounts of phosphate are precipitated in the form of dicalcium phosphate (14, 44), and subsequently more stable, complex forms as $H_6K_3Al_5(PO_4)_8 \cdot 18H_2O$, and $H_8K(Al,Fe)_3(PO_4)_6 \cdot 6\ H_2O$ (48, 49).

Moreover, the phosphate ion can also be adsorbed on the surface of calcium carbonate particles or Ca-dominated clay particles. It appears that the activity of P will be lowered in those soils having a high Ca activity, either as a result of a large amount of finely divided calcium carbonate or due to a large amount of Ca-saturated clay.

On the other hand, although soil phosphates are fixed into insoluble forms, the fact that a large amount of fixed P becomes available to plants implies that certain mechanisms occurring in soils can solubilize the phosphates to a significant extent. The mechanism which is considered as the most important one in this respect is the chelating action of organic acids, which originates from the decomposition of organic matter and the excretion of microorganisms. It was reported that humic acid, the final product of decomposed plant residues, can reduce the fixing ability of certain metal ions such as Fe and Al (57); and it was also believed that this kind of organic acid complex in soils can hold the P in exchangeable form (7). Many researchers were in agreement that organic matter reduced the amount of P fixed by certain acid soils (18, 19, 27, 32). Conversely, other work has shown that removal of the humus from soil by leaching with NaOH did not reduce the fixing capacity of the soil (69).

Dean and Rubins (17) studied the replacing power of various anions and suggested that the order was hydroxide $>$ citrate $>$ fluoride $>$ tartrate $>$ arsenate $>$ acetate. Swenson et al (76) suggested the fixed P was released by anions in the following order: fluoride $>$ oxalate $>$ citrate $>$ bicarbonate $>$ borate $>$ acetate $>$ thiocyanide $>$ sulfate $>$ chloride. They further supposed that the ability of organic matter to replace P originated from organic acids, and that the ability of these organic acids to extract phosphate from soil particles was due to their properties of forming stable complexes with Fe and Al. Struthers and Sieling (74) proposed that the beneficial action of organic matter in the soil could be attributed to several sources:

a. The protective action of organic colloids in preventing soluble P from coming into contact with the active Fe and Al.

b. The action of CO_2 produced during the decomposition of organic matter in dissolving certain P material or in "tying up" the active Fe.

c. Formation of organic phosphate compounds, which are less firmly fixed by soils than are inorganic phosphate compounds.

d. Decomposition of organic matter containing P accompanied with the release of P for plant use.

They chose several organic acids of agricultural importance such as citric acid, tartaric acid, oxalic acid, malic acid and succinic acid, to determine whether the organic anion would affect the fixation of P in solution at different pH values. Their results showed that the presence of hydroxyl groups was an important factor in the ability of a dicarboxylic acid to prevent P from precipitation by Fe and Al, whereas organic acids with one hydroxyl group had greater effects on the solubilization of P when it contained three carboxylic groups. Therefore, tricarboxylic acid, such as citric acid was tremendously effective in preventing P from precipitation at pH 4.0 to 6.0.

Swaby and Sherer (75) and Louw and Webley (51) pointed out that microorganisms could dissolve mineral phosphates in soil. In fact, it was very likely that the organic acids excreted by microorganisms solubilized the phosphates by the same mechanism previously described. However, microorganisms play an important role in peat formation and decomposition (28, 73, 85).

EXPERIMENTAL PROCEDURE

Field Experiment

A virgin Houghton muck located at the Michigan State University Muck Experimental Farm in Clinton County was broken up in 1963. It was divided into two blocks with eight plots in each block, as shown in Figure 1. Onions and potatoes were planted with different rates of P. All plots, except the "no fertilizer" treatment, received 415 pounds of K, 50 pounds of N and 20 pounds of Mn per acre. The P treatments designated as P_o, P_1, P_2, P_3 and P_4, correspond to 0, 11, 22, 44, and 88 pounds of P per acre. All treatments were randomized and replicated two times (Figure 1). Onions (var. Downing Yellow Globe) and potatoes (var. Sebago) were planted in May and harvested the latter part of September in 1963, 1964 and 1965. The yields were obtained and recorded in hundred weights per acre.

The green potato and onion tissue were sampled six weeks after planting in 1963 and P determined on the green tissue. Approximately 40 potato petioles and 40 onion leaves per plot were taken to represent a composite sample. The petiole of the fourth potato leaf from the growing tip was selected in all cases. The soils were sampled in the spring of 1963, 1964 and 1965. Available

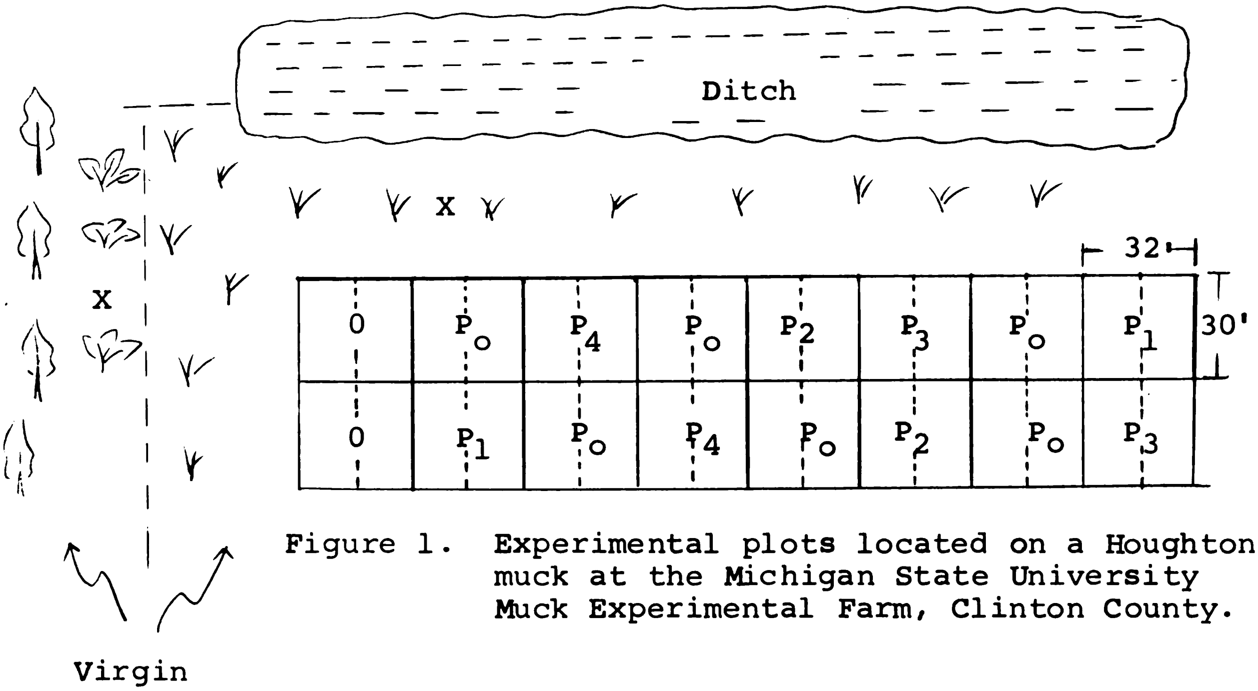

Figure 1. Experimental plots located on a Houghton muck at the Michigan State University Muck Experimental Farm, Clinton County.

All plots except the control plot (designated as 0) received 50 pounds per acre of N, 415 pounds per acre of K and 20 pounds per acre of Cu and Mn.

The following P treatments were randomized and replicated two times:

P_o = 0 pounds per acre

P_1 = 11 pounds per acre

P_2 = 22 pounds per acre

P_3 = 44 pounds per acre

P_4 = 88 pounds per acre

Soil samples were obtained from the virgin area (X) and the experimental plots.

P (0.025 N HCl + 0.03 N NH_4F extractable) was determined by the Michigan State University Soil Testing Laboratory on a composite sample consisting of 20 subsamples per plot. Total P was determined on a representative sample of the potato tissue (petiole) in 1963. The oven-dried tissue was ashed at 550°C. and P determined spectrographically.

Laboratory Experiment

Determination of Organic and Inorganic Soil Phosphorus

Sample

Seventeen soil samples were obtained from the virgin area and the plots receiving the different P treatments (Figure 1). These samples represented seven different areas, namely, virgin, "no fertilizer" treatment, and P_0, P_1, P_2, P_3, P_4 treatments. The soils were air-dried and sieved through an 80-mesh sieve.

Extraction

One gram of air-dried soil was placed in a beaker to which 10 ml of 6 N HCl were added. The beaker was heated at about 90°C. on a steam plate for 10 minutes, and then allowed to stand for one hour at room temperature with an additional 10 ml of 6 N HCl. The acidified suspension was collected and washed with 50 ml of distilled water into a 100 ml centrifuge tube, centrifuged at high speed and the supernatant liquid decanted into a 250 ml volumetric flask. The sediment was washed with 30 ml of distilled water and added to the supernatant liquid, and 30 ml of 0.5 N NaOH were added to the washed residue, shaken for 10 minutes, centrifuged, and the supernatant added to the acidified portion. The residue was then suspended with 60 ml of 0.5 N NaOH and heated at approximately 90°C. in a waterbath for 8 hours. After digestion the suspension was centrifuged and the supernatant was decanted to the volumetric flask, and made to volume with distilled water.

Digestion for Determination of Total Phosphorus

The extract was thoroughly mixed and 20 ml aliquots were placed in tall-form beakers, and 10 ml of concentrated HNO_3 followed by 5 ml of 72 percent perchloric acid were added. The solution was heated on a hot plate at a temperature below 160°C. until most of the concentrated HNO_3 had been dispelled, covered with a ribbed-watch glass, and the temperature increased. The solutions were removed from the hot plate as they approached dryness, distilled H_2O added and made to a final volume of 50 ml. A 10 ml aliquot was taken for the determination of total P.

Inorganic Phosphorus Determination In the Extract Solution

The original extract was allowed to stand until all of the flocculates sedimented. A 5 ml aliquot of the supernatant liquid was taken for the determination of inorganic P.

Phosphorus Measurement by the Chloromolybdate Method

The standard curve was prepared by pipetting 1, 2, 4 and 8 ml of 5 ppm P solution into four 50 ml volumetric flasks containing a small portion of water. The pH was adjusted to 3 with 4 N NH_4OH and 0.5 N HCl using para-nitrophenol as the indicator. The blue color was developed by adding 10 ml of 1.5 percent ammonium molybdate reagent and 5 drops of 5 percent freshly prepared stannous chloride. The solution was made to volume and the percent transmission read on a Spectronic 20 colorimeter at a wavelength of 620 millimicrons.

The same procedure was followed for the determination of total P and inorganic P except that 5 drops of 1000 ppm citric acid solution were added before the pH was adjusted for the inorganic P determination.

Organic Phosphorus Determination

The organic P was obtained by subtracting the inorganic P from the total P.

$$\text{Organic P} = \text{Total P} - \text{Inorganic P}$$

$$\%\ \text{Organic P} = \frac{\text{Organic P}}{\text{Total P}} \times 100$$

Incubation Study

Soil samples were obtained from the uncultivated (virgin) and cultivated areas of the experimental plots (Figure 1). The sample from the cultivated plots had received 264 pounds of P per acre over a three-year period.

The virgin muck soil was treated with 0, 25, 50, 200, 400 ppm of P and incubated for 1, 2, 4, 6 and 8 weeks. All treatments were carried out in triplicate and each treatment received 300 ppm of N as $(NH_4)_2SO_4$ and 20,000 ppm of sucrose. Two levels of P, 0 and 400 ppm, were added to the sample of cultivated muck soil and incubated for the same period as the virgin soil samples.

One gram samples of the air-dried soils were placed in flat-bottomed test tubes and raised to 50 percent water holding capacity. The tubes were covered with a thin layer of polyethylene and incubated at 30^{o}C. The five groups of samples were analyzed for P at 1, 2, 4, 6 and 8 week periods. Similar analysis for the check samples (without incubation) was carried out in duplicate following the same procedure.

Leaching Study

This study was initiated to determine the relative P fixing capacities of the uncultivated (virgin) soil and cultivated soils. Four soil samples were chosen for this study. In addition to the virgin soil sample, one sample was obtained from the plot receiving no fertilizer, and the other two samples were selected from plots that had been cultivated for 3 years and approximately 25 years (aging muck) which had received a high annual rate of P application (Section C).

The soils were sieved through a 10-mesh screen and kept moist in sealed polyethylene sacks. The moisture content of each soil sample was determined and an amount of soil equivalent to 500 grams on a dry-weight basis was prepared. The soils were placed in four glass columns, 4 inches in diameter and 17 inches long. The bottom end of the column was tapered to facilitate the attachment of rubber tubing. A layer of glass wool was placed at the bottom of the column, and a rubber tube equipped with a pinch-clamp was used to regulate the flow of water. The soils were placed in the columns, the top of which was sealed with a sheet of polyethylene paper while a small hole, large enough to facilitate a rubber tube, was bored in the polyethylene. Distilled water was delivered into the column and the rate of flow adjusted to 1 drop every 2 to 3 seconds. Leaching was discontinued after a total of 1000 ml of leachate had been collected. Excessive free water in the columns was released.

About 0.1 millicurie of radioactive P^{32}, which was carried in 100 ppm of P in the form of phosphoric acid, was incorporated into a 100-gram portion (on a dry weight basis) of each of the four soils. Each soil was moistened, thoroughly mixed and placed on top of the soil contained in the respective columns. The columns were covered with polyethylene and allowed to incubate at room temperature for 7 days.

At the end of this period, the soil was leached with distilled water as described previously. Four additional soil columns were leached with 0.05 N HCl in the same manner as was described for the water leachate. However, the leaching was carried out after the soils had incubated for 20 days. Each 100 ml of leachate was collected as a fraction, and 20 fractions from each soil were gathered. To determine the radioactivities of these fractions, 2 ml of the leachate was pipetted into a small aluminum planchet, and then evaporated to dryness on a hot plate. Radioactivity was counted on a NMC Model DS-L Decade Scaler.

If the counts were very low, several fractions were combined, and a larger aliquot of the leachate was taken. Due to the extremely low counts of the leachates, the twenty fractions were combined. Exactly 1000 ml of the leachates were placed in 1000-ml beakers, and 20 ml of concentrated nitric acid added. The solutions were evaporated until only 50 ml remained, and then transferred to 50-ml beakers. The leachates were concentrated to 20 ml by heating, and transferred dropwise into aluminum dishes on the hot plate and evaporated to dryness. The dry leachates were counted.

RESULTS AND DISCUSSION

The effects of applied P on the yield of onions and potatoes grown on a virgin Houghton muck in 1963, 1964, and 1965 are shown in Table 1 and Figures 2 and 3, respectively.

Onion yields obtained from the plots receiving 22 and 88 pounds of P per acre in 1963 were significantly greater than those obtained from the plots receiving no treatment; and the 88 pounds of applied P per acre gave significantly higher yields of onions than did the 11 pound P treatment (Table 1).

In 1964, however, no significant differences were observed in the yield of onions and the various P treatments.

The plots receiving 22 and 44 pounds of P per acre in 1965 gave significantly higher onion yields than the plots receiving no P application.

The application of 88 pounds of P per acre in 1963 significantly depressed the yield of potatoes over the 11, 22 and 44 pound application rates (Table 2). No significant differences were obtained among P treatments and potato yields in 1964. While in 1965, the 44 pound P application rate gave significantly higher potato yields than the plots receiving the Po treatment.

The relationships among the soil applied P, the parts per million of P in the green potato and onion tissue

Table 1. The effect of applied phosphorus on the yield of onions in 1963, 1964 and 1965.

Treatment* N-P-K Pounds per Acre	1963 Yield Cwt. per Acre	1964 Yield Cwt. per Acre	1965 Yield Cwt. per Acre
50- 0-415	497	416	417
50-11-415	540	356	639
50-22-415	596	392	651
50-44-415	559	333	651
50-88-415	639	377	597
L.S.D. (5% level)	84.6	111.5	233.8

*All fertilizers except 11 pounds of phosphorus were broadcast.

Table 2. The effect of applied phosphorus on the yield of potatoes in 1963, 1964 and 1965.

Treatment N-P-K Pounds per Acre	1963 Yield Cwt. per Acre	1964 Yield Cwt. per Acre	1965 Yield Cwt. per Acre
50- 0-415	256	227	240
50-11-415	270	227	301
50-22-415	269	239	322
50-44-415	266	272	355
50-88-415	228	189	314
L.S.D. (5% level)	38.2	106.4	90.9

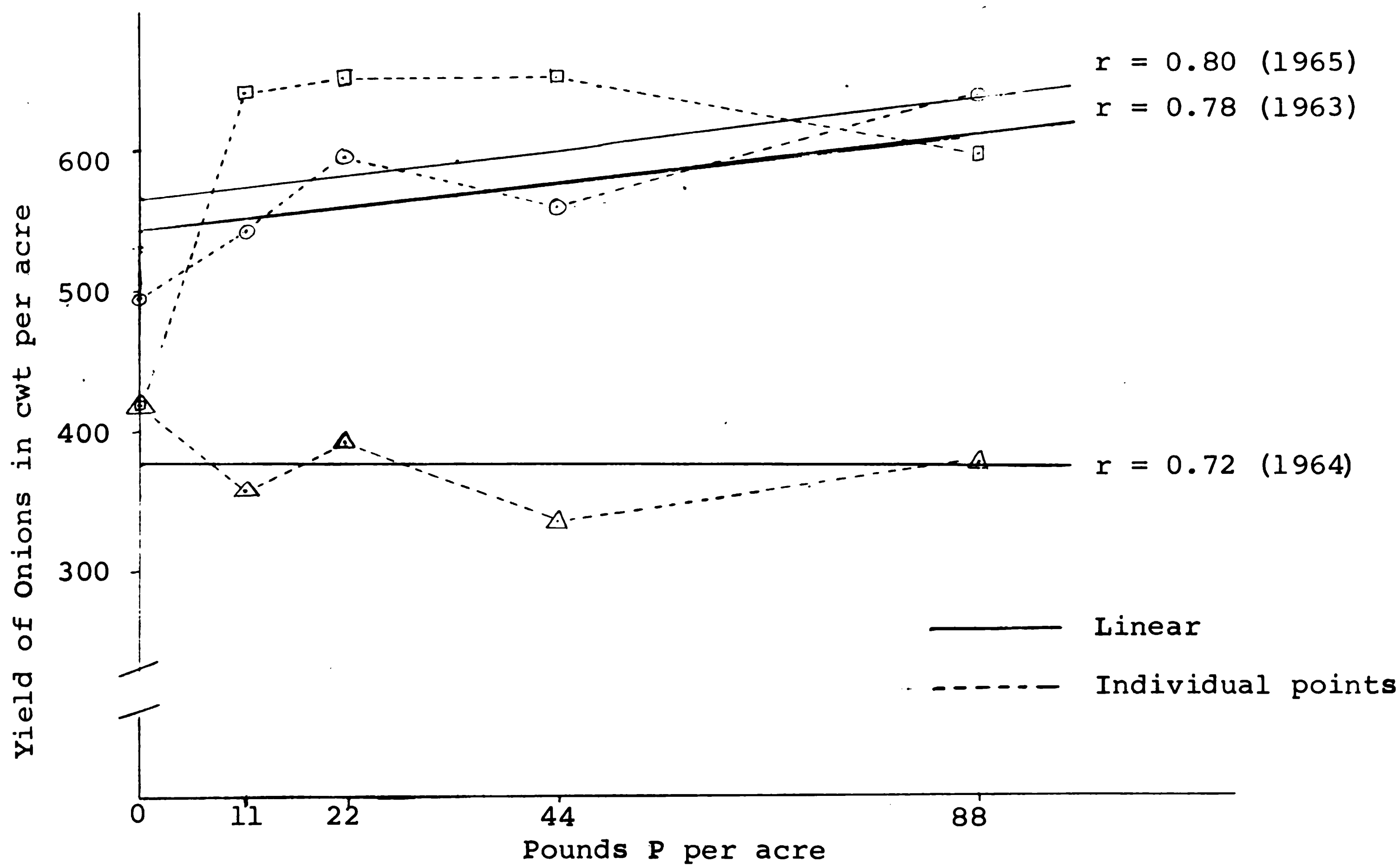

Figure 2. The relationship between the yield of onions and applied soil phosphorus in 1963, 1964 and 1965

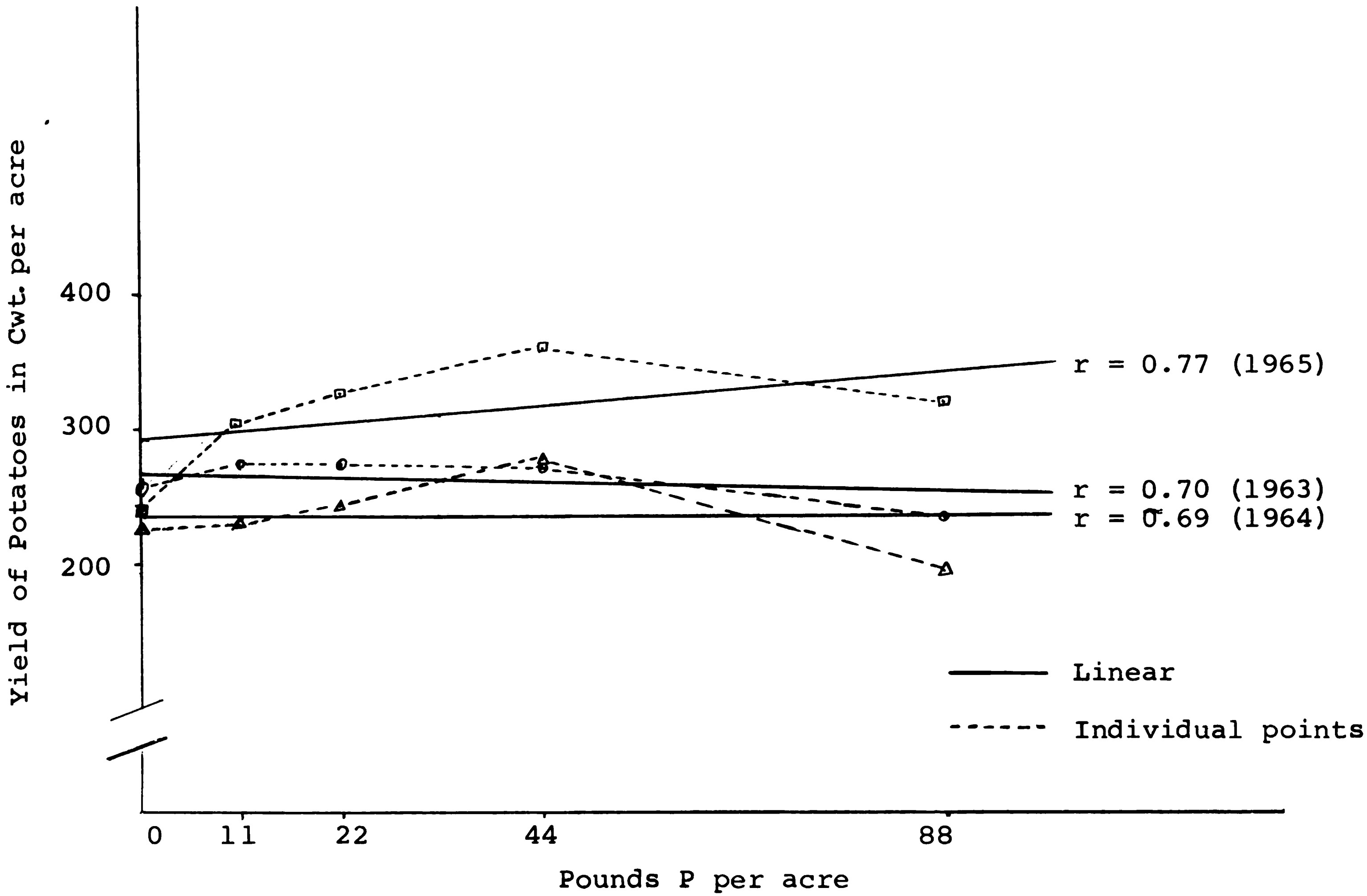

Figure 3. The relationship between the yield of potatoes and applied soil phosphorus in 1963, 1964 and 1965.

and the yields of these two crops in 1963 are shown in Tables 3 and 4 and Figures 4 and 5, respectively.

It is apparent from these data that the onions grown on a virgin muck low in available P (9 pounds per acre of Bray P_1, extractable) responded to P much better than potatoes. Receiving 11 and 22 pounds of P per acre, No. 1 potatoes increased by 10 and 11 hundred weight per acre respectively over plots receiving no P. Onions receiving these levels of applied P increased 43 and 99 hundred weight respectively. The plots receiving no fertilizers produced only 161 and 36 hundred weight per acre of potatoes and onions, respectively (Tables 3 and 4).

When 415 pounds of K per acre was added, yields increased 191 and 336 cwt. per acre, respectively. The soil test level of K was approximately 50 pounds per acre (1 N NH_4OAc extractable).

As shown in Tables 3 and 4 and Figures 4 and 5 the P in the green plant tissue of both onions and potatoes generally increased with increasing levels of applied P. A decrease in potato yield resulted from the 88 pounds P application rate. This was accompanied by an increase of P in the green potato tissue (Figure 5). It is possible that the high levels of applied P created an unbalanced soil condition and induced a deficiency of some other element or elements essential for growth and optimum yields. As shown in Table 5, increased levels of applied P generally resulted in a decrease of Zn in the potato tissue. The

Table 3. The effect of phosphorus treatments on the yield and amount of phosphorus in green onion tissue 6 weeks after planting, 1963.

Pounds per acre P + K*	P in green onion leaves Parts per million	Yield in cwt. per acre
0 + 0	34.0	161
0 + 415	31.5	497
11 + 415	37.5	540
22 + 415	42.5	596
44 + 415	33.5	559
88 + 415	39.0	639

*All plots exclusive of the unfertilized plots received 50 pounds of N and 20 pounds of Mn per acre as a broadcast application. All values are averages of two replications.

Table 4. The effect of phosphorus treatment on the amount of phosphorus in green potato petioles 6 weeks after planting, 1963.

Pounds per acre P + K*	P in green potato petioles Parts per million	Yield in cwt. per acre**
0 + 0	118.5	36
0 + 415	61.0	227
11 + 415	60.5	237
22 + 415	57.0	238
44 + 415	80.5	238
88 + 415	129.0	193

*All plots exclusive of the unfertilized plots received 50 pounds of N and 20 pounds of Mn per acre as a broadcast application.

**No. 1 potatoes low yields caused by June frost, 1963.

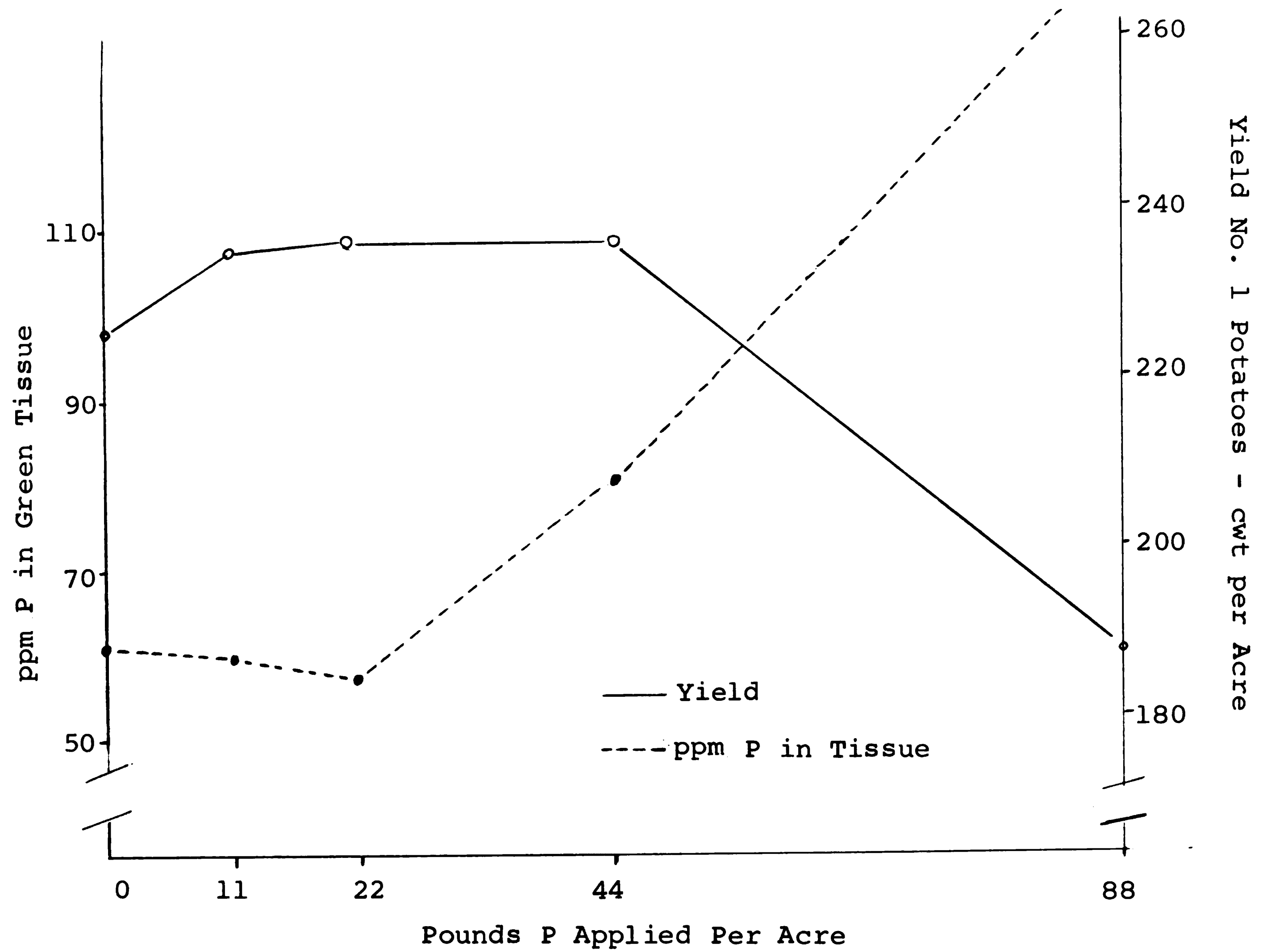

Figure 4. The relationships among the phosphorus applications, phosphorus in the green tissue (6 weeks), and the yield of No. 1 potatoes, 1963.

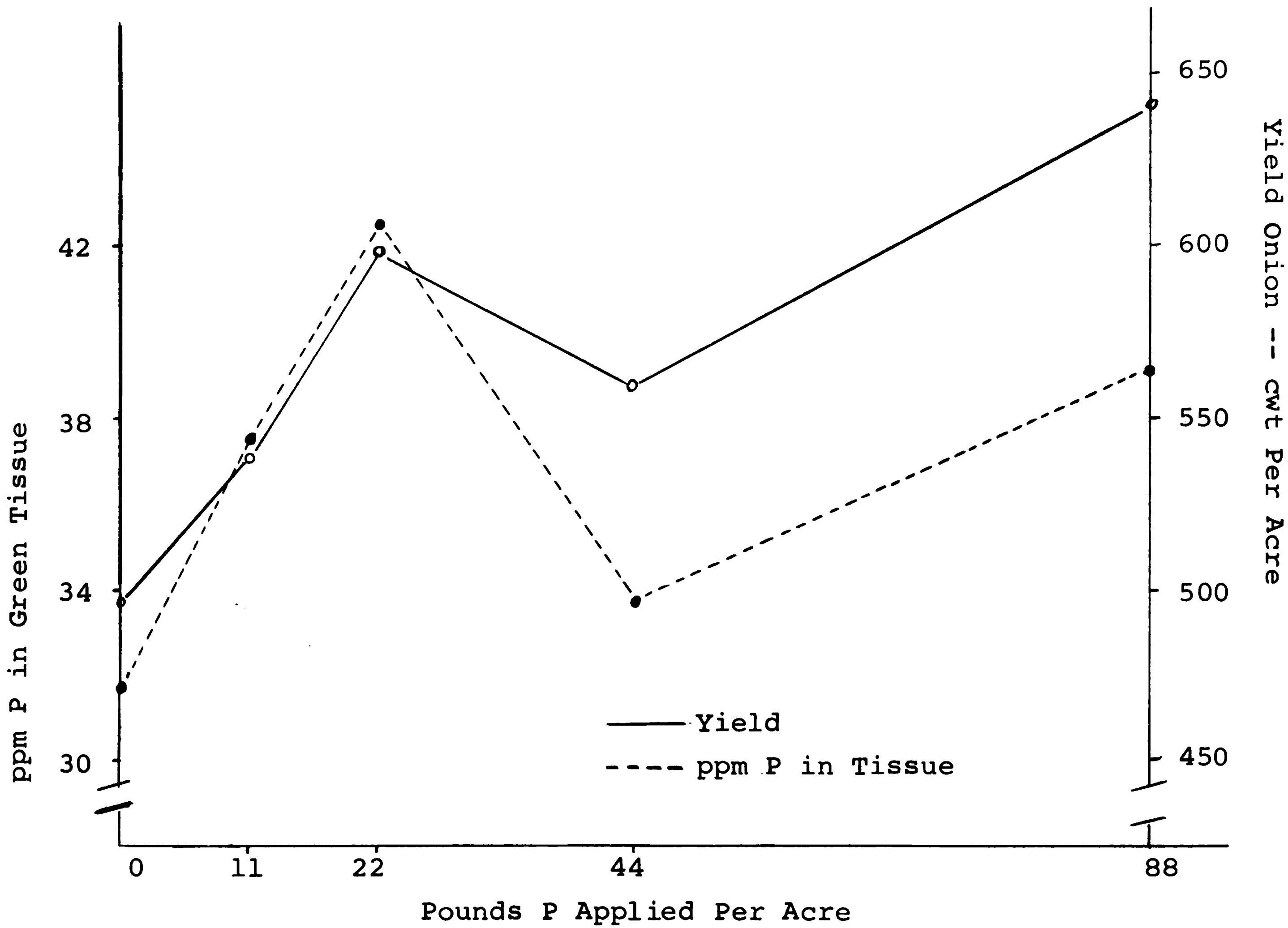

Figure 5. The relationships among phosphorus applications, phosphorus in the green tissue (6 weeks), and the yield of onions.

Table 5. The influence of phosphorus treatment on the yield and iron, copper, boron, molybdenum and zinc content of potatoes, 1963.

Treatment Pounds P per acre	P Percent	Mn	Fe	Cu	B	Mo	Zn	Yield cwt. per acre
		ppm						
0	0.486	687	267	12.4	31.3	5.5	81	256
11	0.501	614	266	12.9	29.5	5.8	79	270
22	0.471	712	256	12.0	33.0	6.5	71	269
44	*	*	*	*	*	*	*	266
88	0.502	627	200	12.0	26.0	5.2	54	228

*No sample taken.

tissue obtained from the plots receiving 88 pounds of P per acre contained about 33.3 percent less zinc than those obtained from the plots receiving no phosphorus. The total P in the tissue, however, did not vary appreciably (Table 5).

The tremendous response of both onions and potatoes to soil applied K in 1963 is shown in Tables 3 and 4. The application of 415 pounds of K per acre on the P_0 plots increased the yields of onions and potatoes from 161 and 36 cwt. per acre to 497 and 227 cwt. per acre, respectively.

The application of 11 pounds of P per acre, on the plots receiving 415 pounds of K, increased onion yields by almost 9 percent. Only a slight increase (about 4 percent) was obtained in the yield of potatoes with this rate of applied P (Table 4) even though the soil contained only 9 pounds of available P. The response of potatoes to 11 pounds of P per acre appeared to be a "starter" effect. No additional response resulted from the 22 and 44 pound application rates and a decrease in yield resulted, as pointed out previously, where 88 pounds of P was applied per acre.

An attempt was also made to apply the mobility or elasticity concept to these data as proposed by Bray (8a) according to the following equation:

$$\log (A-Y) = \log A - c_1 b \quad (1)$$

where A = the maximum yield of onions and/or potatoes. Bray defined A as the yield possibility when all nutrients are present in adequate quantity but not in harmful excess, provided all other immobile nutrients remain unchanged and nitrogen is adequate; Y = the yield of onions and/or potatoes when no P is applied but other nutrients are present in adequate amounts; b = the amount of soil P present as determined by the Bray P_1 soil test; and C_1 = proportionality constant which was determined experimentally.

The C_1 values obtained for onions and potatoes are shown in Table 6; and the relationships between Bray P_1 extractable soil P and the percentage yield of onions and potatoes for 1963, 1964 and 1965 are shown in Figures 6, 7, 8, 9, 10 and 11.

The value for one Baule unit of soil P (Table 7) was determined from equation (1) using the experimentally determined C_1 values, as shown in Table 6. A Baule unit of soil P may be defined as the amount of soil P necessary to produce a yield that is 50 percent of the maximum possible yield.

The Baule units of soil P for the onion crop varied from 2.7 to 4.8 with an average value of 3.5. There was less variation in the Baule units of soil P for potatoes (2.0 to 3.4) with a mean value of 2.6.

The interpretation of these data indicate that 50 percent of the maximum yield of onions and potatoes would be obtained at P soil test levels of 4.1 and 2.0, respectively on the virgin muck (1963 data). While in 1965, after 3 years of cultivation, 4.8 and 2.6 pounds of Bray P_1 extractable soil P would be required to obtain 50 percent of the maximum yields of these crops. The equivalent yields (percent) for

Table 6. The calculated c_1 values for onions and potatoes grown on a Houghton muck in 1963, 1964, and 1965.

Crop	C_1 values*		
	1963	1964	1965
Onions	0.0732	0.1110	0.0627
Potatoes	0.1470	0.0870	0.1170

*Average of 8 values.

Table 7. Baule units of soil phosphorus (Bray P_1 extractable) for onions and potatoes grown on a Houghton muck over a 3-year period.

	Pounds of soil P per Baule unit of soil P		
Crop	1963	1964	1965
Onions	4.1	2.7	4.8
Potatoes	2.0	3.4	2.6

For further references, see

[1]Spurway, C. H. 1948. Soil Fertility Diagnosis and Control for Field, Garden and Greenhouse Soils. Edwards Brothers, Inc. Ann Arbor, Michigan.

[2]Willcox, D. W. 1937. The ABC of Agrociology. W. W. Norton and Company, Inc., New York.

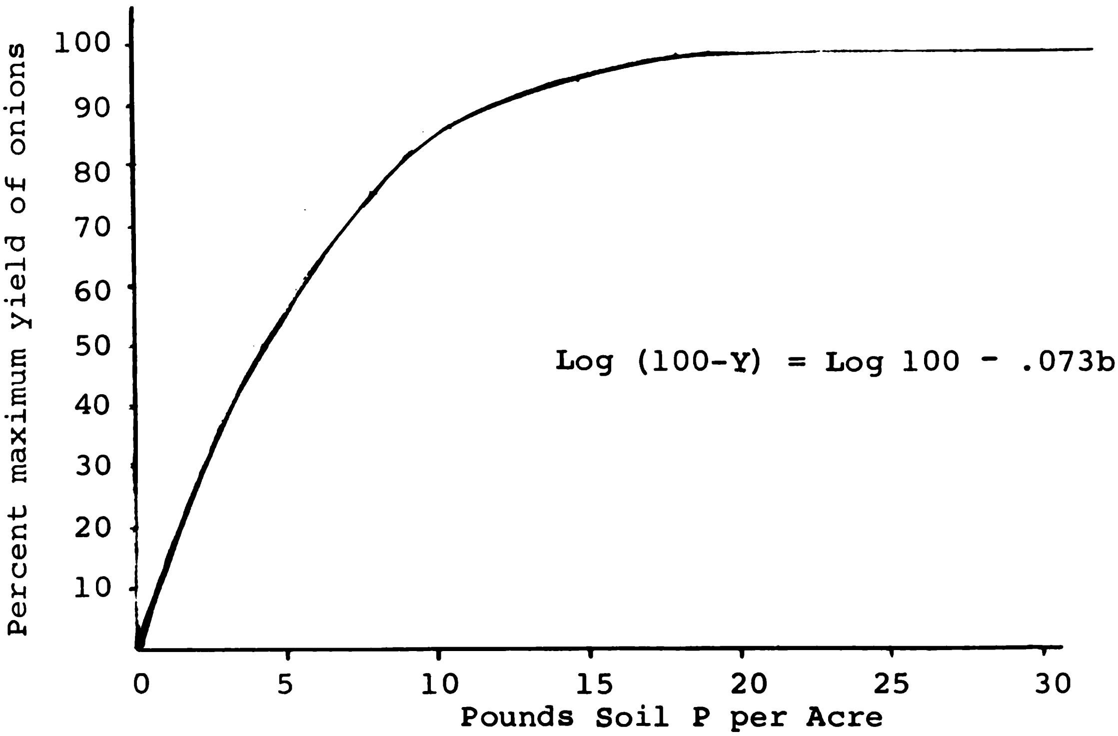

Figure 6. The relationship between Bray P_1 extractable soil P and the yield of onions, 1963.

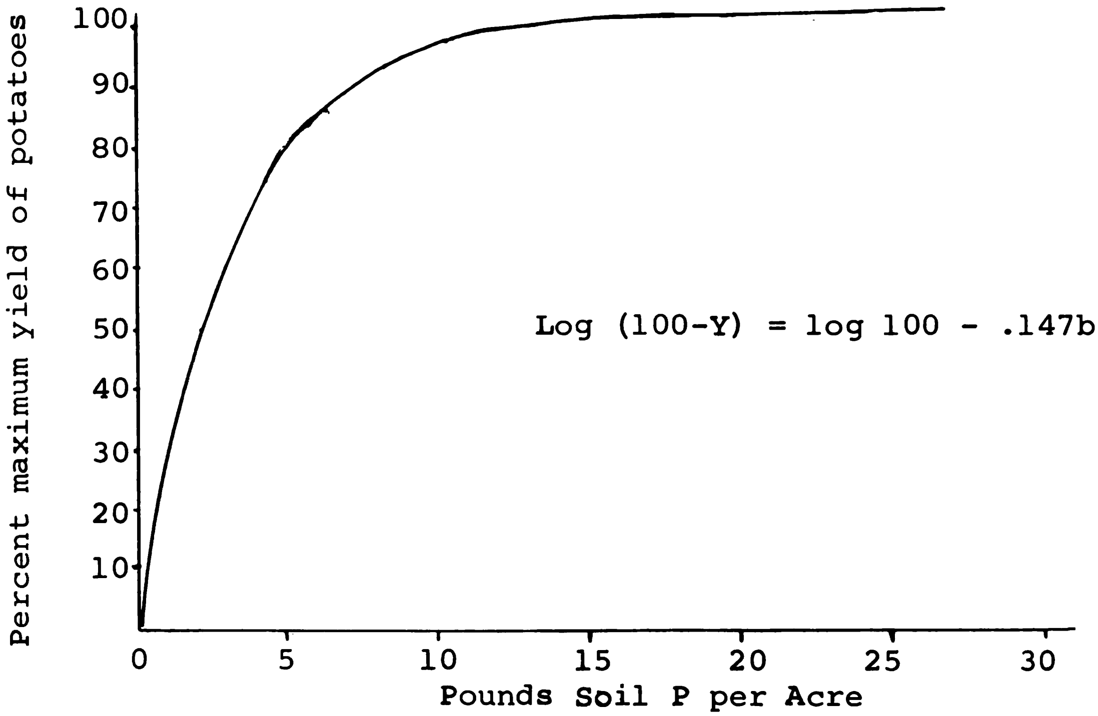

Figure 7. The relationship between Bray P_1 extractable soil P and the yield of potatoes, 1963.

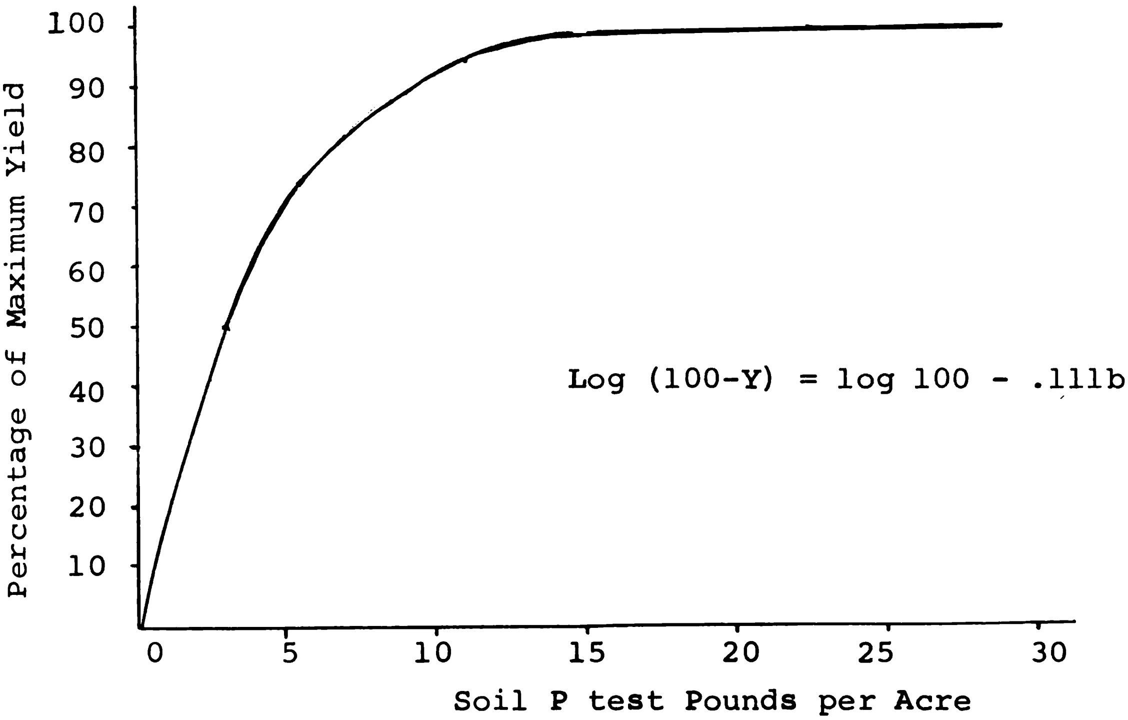

Figure 8. The relationship between Bray P_1 extractable soil P and the yield of onions, 1964.

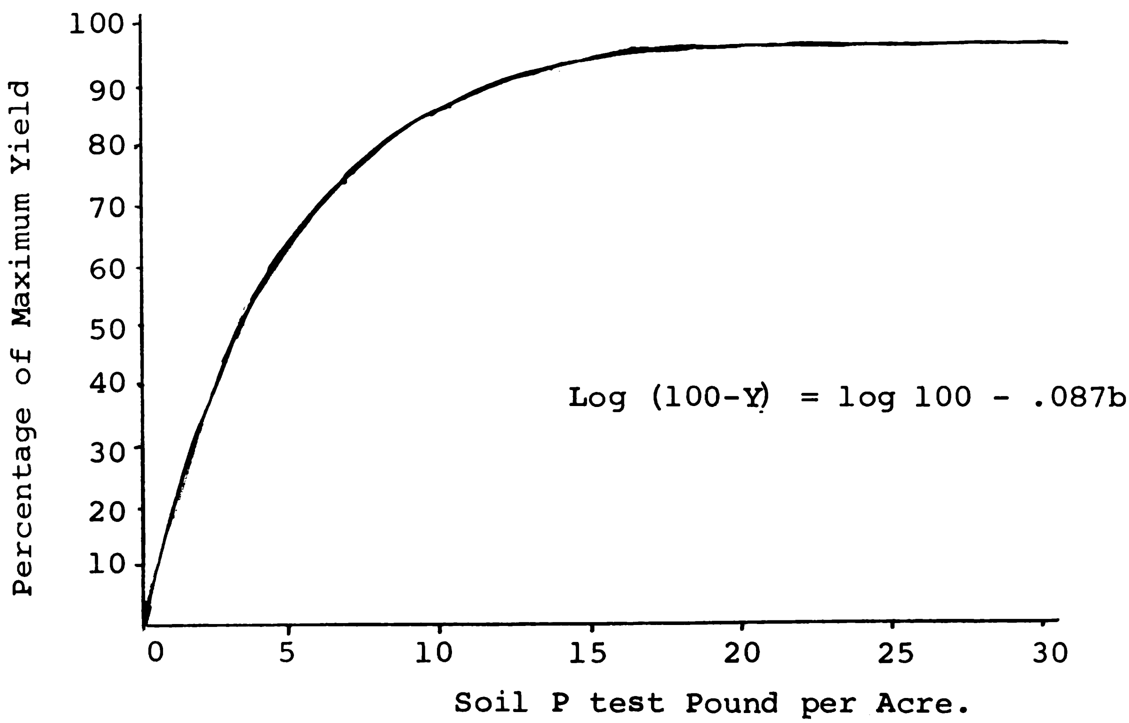

Figure 9. The relationship between Bray P_1 extractable soil P and the yield of potatoes, 1964.

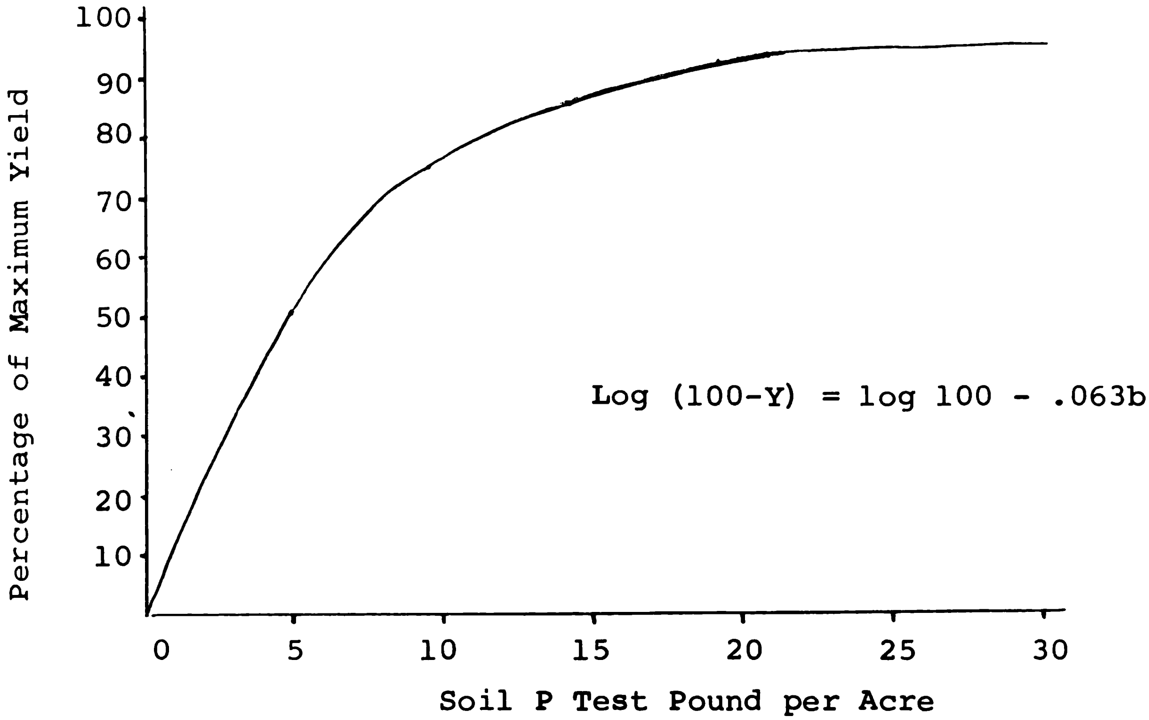

Figure 10. The relationship between Bray P_1 extractable soil P and the yield of onions, 1965.

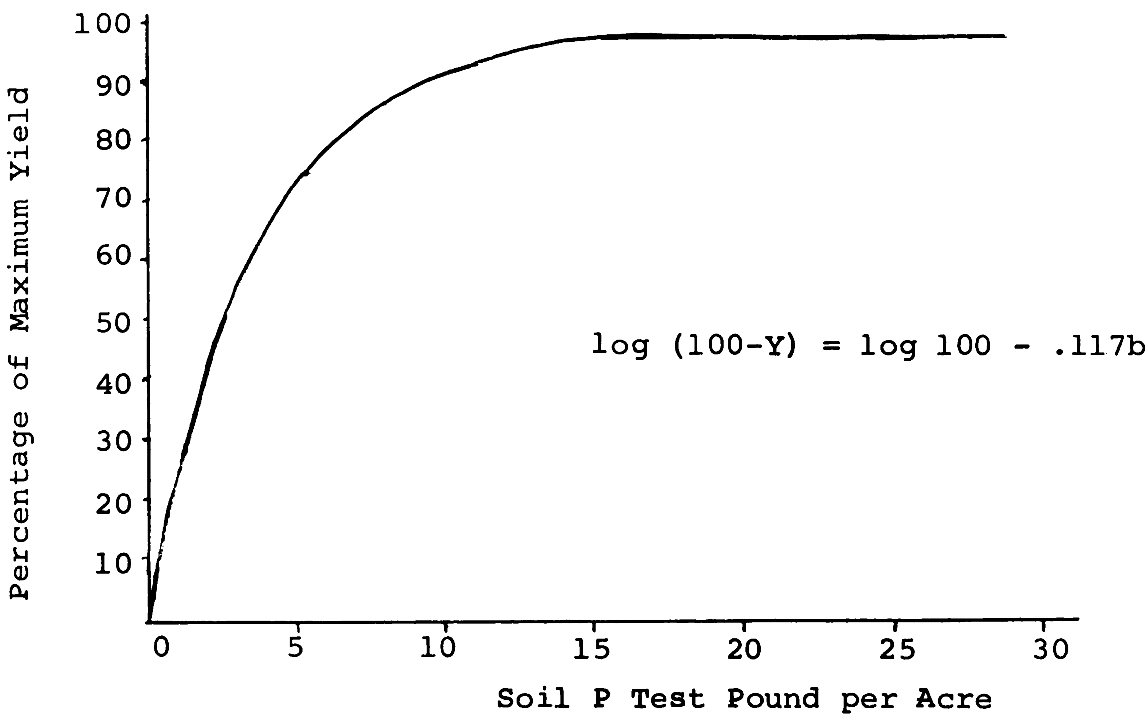

Figure 11. The relationship between Bray P_1 extractable soil P and the yield of potatoes, 1965.

onions and potatoes relative to the pounds of Bray P_1 extractable soil P for 1963 and 1965 are shown in Tables 8, 9, 10, and 11. These data indicate that 97 percent of the maximum yields of onions and potatoes could be obtained on a virgin muck with soil P levels of approximately 20 and 10 pounds per acre, respectively, and with 24 and 13 pounds per acre, respectively in 1965.

According to Bray, the Mitscherlich equation could be expanded to permit the calculation of the amount of fertilizer needed to raise the percent yield from any given starting level to any other desired upper level for which fertilization was desired (8a). He derived the following equation:

$$\text{Log } (A-Y) = \log A - c_1 b - cx \quad (2)$$

where, C = the efficiency factor of the method of applying the fertilizer, and x = the quantity of fertilizer, of the form of nutrient b, that need be added for a desired percentage yield.

The yield of onions and potatoes obtained in 1963, 1964, and 1965 from the P rate experiments were substituted in equation (2) as a basis for determining c, the fertilizer P efficiency factor. The following equations were derived and the calculated c values for onions and potatoes for the 3-year period are shown in Table 12.

$$\text{Log } (A-Y) = \log A - .0732b - .0265\ x \quad (3) \quad 0 - \text{'}63^*$$

$$\text{Log } (A-y) = \log A - .1470b - .0163\ x \quad (4) \quad P - \text{'}63^*$$

$$\text{Log } (A-Y) = \log A - .1110b + .1679\ x \quad (5) \quad 0 - \text{'}64$$

Table 8. Phosphorus requirement for onions grown on a virgin Houghton muck, 1963.

Soil P Test* Pounds per Acre	Equivalent Yield Percent	Fertilizer Requirement Pounds per Acre P	P_2O_5
4.1	50	47.6	109.5
8.2	75	35.7	82.1
12.3	87	23.8	54.7
16.4	94	11.9	27.4
20.5	97	0	0

*Bray P_1 extractable.
1 Baule unit of soil P (soil test) = 4.1 pounds per acre.
1 Baule unit of fertilizer P = 11.9 pounds per acre.
1 Baule unit of fertilizer P_2O_5 = 27.4 pounds per acre.

Table 9. Phosphorus requirements for potatoes grown on a virgin Houghton muck, 1963.

Soil P Test* Pounds per Acre	Equivalent Yield Percent	Fertilizer Requirements Pounds per Acre P	P_2O_5
2.0	50	74.0	170.2
4.1	75	55.5	127.7
6.1	87	37.0	85.1
8.2	94	18.5	42.6
10.2	97	0	0

*Bray P_1 extractable.
1 Baule unit of soil P (soil test) = 2.0 pounds per acre.
1 Baule unit of fertilizer P = 18.5 pounds per acre.
1 Baule unit of fertilizer P_2O_5 = 42.6 pounds per acre.

Table 10. Phosphorus requirement for onions grown on a Houghton muck, 1965.

Soil P Test* Pounds per Acre	Equivalent Yield Percent	Fertilizer Requirement Pounds per Acre P	P_2O_5
4.8	50	41.2	94.8
9.6	75	30.9	71.1
14.4	87	20.6	47.4
19.2	94	10.3	23.7
24.0	97	0	0

*Bray P_1 extractable.
1 Baule unit of soil P (soil test) = 4.8 pounds per acre.
1 Baule unit of fertilizer P = 10.3 pounds per acre.
1 Baule unit of fertilizer P_2O_5 = 23.7 pounds per acre.

Table 11. Phosphorus requirement for potatoes grown on a Houghton muck, 1965.

Soil P Test* Pounds per Acre	Equivalent Yield Percent	Fertilizer Requirement Pounds per Acre P	P_2O_5
2.6	50	94.0	216.2
5.2	75	70.5	143.2
7.8	87	47.0	108.1
10.4	94	23.5	54.0
13.0	97	0	0

*Bray P_1 extractable.
1 Baule unit soil P (soil test) = 2.6 pounds per acre.
1 Baule unit fertilizer P = 23.5 pounds per acre.
1 Baule unit fertilizer P_2O_5 = 54.0 pounds per acre.

Table 12. Calculated c values for onions and potatoes grown on a Houghton Muck, 1963, 1964 and 1965.

Crop	c values* 1963	1964	1965
Onions	0.0265	-0.1679	0.0293
Potatoes	0.0163	-0.0129	0.0128

*Average of 8 values.

$$\text{Log } (A-Y) = \log A - .0870b + .0129 \times \quad (6) \quad P - '64$$

$$\text{Log } (A-Y) = \log A - .0627b - .0293 \times \quad (7) \quad O - '65$$

$$\text{Log } (A-Y) = \log A - .1170b - .0128 \times \quad (8) \quad P - '65$$

*O = onions, 1963; P = potatoes, 1963

From equations 3 through 8 the Baule units of fertilizer P were calculated, and the fertilizer P requirement for 97 percent maximum yield of onions and potatoes at various soil P levels were determined (Tables 8, 9, 10 and 11).

The experimentally determined c values for 1964 were negative (Table 12). This is the result of the negative response of onions and potatoes to applied fertilizer P (Tables 1 and 2). For this reason the Baule units of soil and fertilizer P were not determined. The crops were hit by frost on June 2 and 16 and on August 28, 1964. This undoubtedly affected the growth and subsequent yields of both crops, particularly potatoes. Similar frost periods occurred in 1963 and 1965. Air temperatures of 32°F and 30°F occurred on June 21 and 22, 1963, respectively. This resulted in lower potato yields. Frost also occurred on May 30 and August 3, 1965 with temperatures of 28°F and 31°F, respectively.

Observations by Lucas* at the Michigan Muck Experimental Farm have indicated that onion seedlings can withstand temperatures as low as 25°F. The modified Mitscherlich concept, as proposed by Bray (8a), claimed that crop yields obey the percentage sufficiency concept of Mitscherlich for such elements as P and K which are relatively immobile in the soil. This concept was based on Bray's nutrient mobility concept which states that as the mobility of a nutrient in the soil decreases, the amount of that nutrient needed in the soil to produce a maximum yield (the soil nutrient requirement) increases from a variable net value (determined principally by the magnitude of the yield and the optimum percentage composition of the crop) to an amount whose value tends to be constant.

The magnitude of this constant is independent of the yield of the crop provided the kind of plant, planting pattern, and rate and fertility pattern remain constant and that similar soil and seasonal conditions prevail.

The variations among the C_1 and C values for both onions and potatoes over the 3-year period may possibly reflect seasonal variations as well as differences resulting from soil sampling, fertilizer application and harvesting of the crops.

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*Personal communication.

The fact that the crops were subjected to frost damage at different intensities and at different stages of growth may have differentially retarded the growth of the plants with a subsequent effect on the yield of the crops. Too, this may have affected the plants, to a greater or lesser extent, growing under inadequate or adequate P levels.

The variation that occurred between the C_1 values obtained for potatoes and onions (Table 6) is to be expected since this constant is mainly a function of the rooting pattern of the crop.

As shown in Tables 8, 9, 10, and 11, the P requirement for various yield levels of both onions and potatoes was less on the virgin muck (1963) than on the muck that had been cultivated for 3 years. The work of Kaila (37a) and Paul (60) has explained that mineralization of the organic P present in a virgin organic soil is more rapid than that of a cultivated soil. This would increase the amount of soil P available to the growing plant and subsequently decrease the need of fertilizer P.

The total, inorganic and organic P status of virgin and cultivated Houghton muck is shown in Table 13. An increase in the total P of all soils increased with the application of fertilizer P. The inorganic P content of the virgin soil was less (293 ppm) than the cultivated and fertilized soils. The organic P content of the cultivated soils did not vary appreciably, except for the soils receiving an annual application of 88 pounds of P per acre.

However, the percent organic P decreased with increasing levels of fertilizer P, being highest on the virgin soil (75 percent) and lowest (50 percent) on the soils receiving 88 pounds of P per acre for a 3-year period (Table 13).

The yield of potatoes in 1963, as shown in Table 5, were about equally as good on the non-P fertilized plots as those receiving 11, 22, and 44 pounds per acre. The slight increase in yield (14 cwt. per acre) resulting from the 11 pounds of applied P per acre appeared to be a "starter" effect. The plant composition values for the potato petioles taken in 1963 show that the percent P did not vary appreciably between the plots receiving no P and those receiving up to 88 pounds per acre (Table 5). This possibly indicates that plants growing on the P_o plots were receiving adequate P for optimum yields even though the extractable Bray P_1 phosphorus was low (9 pounds per acre) and that available soil P was the result of the mineralization of organic P to inorganic P.

Nutrients including sucrose were added to all soils before incubation to assure a high level of microbial activity. Changes in inorganic P from one sampling to the next were quite variable. Nevertheless, the linear regressions in Figure 12 show that the general trend was for inorganic P to increase with time. The average increase over an 8-week incubation period was about 100 ppm in virgin muck. In cultivated muck, the rate of release was considerably less. There was no evidence that the increase was dependent upon the amount of soluble P applied.

Table 13. Total, inorganic and organic phosphorus status of virgin and cultivated Houghton muck.

Treatment*	Parts per million P: Total	Inorganic	Organic	Percent Organic P
Virgin	1156	293	863	75
No Fertilizer	1413	460	953	67
P_o	1425	500	925	65
P_1	1407	490	917	65
P_2	1464	548	916	63
P_3	1584	625	959	61
P_4	1736	874	862	50

*For a 3-year period.

Table 14. Changes in the inorganic phosphorus content of incubated virgin and cultivated Houghton mucks.

Treatment	Soluble P Added (ppm)	Incubation period, weeks: 0	1	2	4	6	8
		ppm P**					
Virgin Soil*	0	230	244	300	275	363	330
	25	252	320	324	338	420	359
	50	302	346	352	371	400	422
	200	444	459	448	447	556	552
	400	640	602	716	641	708	738
Cultivated Soil*	0	618	617	639	571	692	607
	400	1061	929	1028	975	1108	990

*Virgin soil refers to sample 18; cultivated soil refers to sample 4 which received 264 pounds of P over a three-year period.

**Extractable in 6 N HCl.

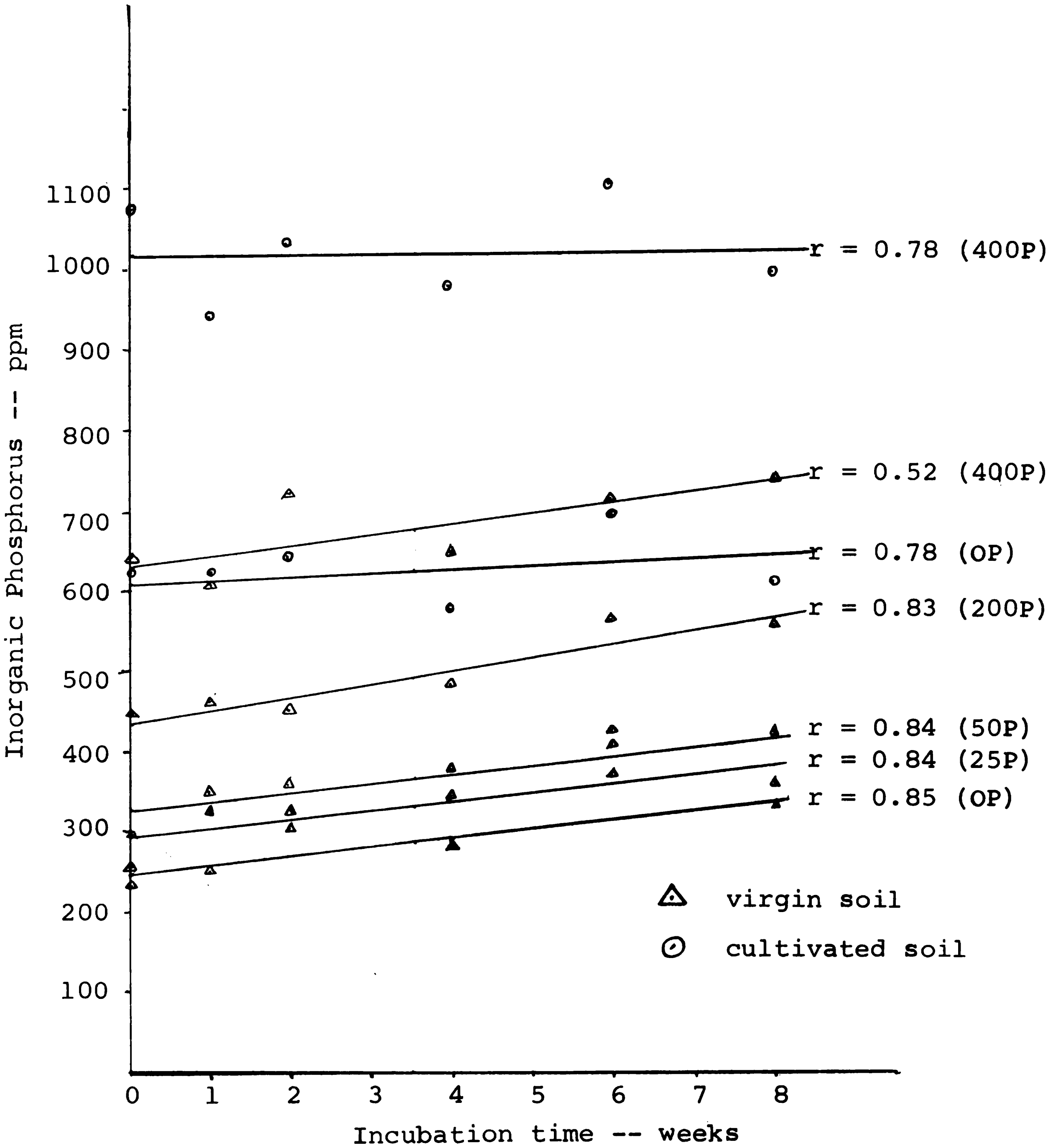

Figure 12. The effect of incubation on the release of inorganic phosphorus on virgin and cultivated Houghton muck soils.

The extensive release in 8 weeks from virgin muck indicates that organic P in this soil when first brought under cultivation may be a significant source of P for plant growth.

Thus, the rate of mineralization of organic P, may have been sufficient to adequately supply inorganic P to the plants during the 1963 growing season. This would account for the lack of response of potatoes to fertilizer P.

The work of Larsen et al (39, 40, 41) has shown that the sesquioxides present in organic soils play an important role in the fixation of soil P Larsen also indicated that organic soils extracted with distilled water gave a better measure of plant available P than dilute hydrochloric acid, and that very little of the inorganic P present in virgin mucks is held in an insoluble form.

The increase in soil fixation of P with an increase in its sesquioxide content has been shown by Larsen et al (41). Muck soils that have been cultivated for long periods of time have higher sesquioxide contents than virgin soils or soils that have been subjected to less cultivation. These phenomena are important in determining the fertilizer efficiency of phosphorus.

As shown in Tables 9 and 11, to obtain 97 percent maximum yield of potatoes the phosphorus requirement increased from 74 pounds per acre in 1963 to 94 pounds per acre in 1965.

It is known that for many mineral soils, due to their high P fixing capacities, the large amounts of fertilizer P are required to obtain optimum yields, and yet, only 20 to 30 percent of the amount applied is recovered.

It is believed that the same conditions exist for organic soils but the extent to which the applied P is fixed and the percentage of applied P recovered is not thoroughly understood.

These data have indicated that the P fertilizer requirements of virgin muck are apparently different from those which have been cultivated. The incubation study also indicated that the virgin soil possessed a greater potential to release P. The virgin soil represents an extreme case where both physical and chemical changes have been less altered than that of cultivated muck soils. The latter group of muck soils have undergone gradual changes as a result of cultivation and management.

The leaching study (Table 15) was initiated to study the effects of varying periods of cultivation and P treatment on the fixation of soil applied P^{32}.

As shown in Table 15, the soils that were cultivated for 3 and 25 years fixed more P^{32} than the virgin muck. The P^{32} obtained in the water leachate from the cultivated soils was only one-fifth to one-third of that obtained in the virgin soil leachate. A comparison of the 3-year cultivated soils shows that the mucks receiving a total of 264 pounds of P per acre fixed less P than the non-fertilized soils. Also, the 25-year cultivated muck soil fixed more of the applied P^{32} than either of the soils that were cultivated for three years.

It is also obvious that most of the applied P^{32} was retained in the soil since the counts per minute of the water leachate were quite low. An interesting point is how tight the P is held by the respective soils. According to preliminary measurements wherein 100-ml fractions of the water leachates were measured, the applied P^{32} was removed with a nearly constant rate. The average rate of P^{32} removal from the virgin soil was higher than that from the cultivated soils.

The .05 N HCl extract of the applied P^{32} shows a 27-fold increase in the retention of P^{32} by the 25-year cultivated soil over the virgin muck (Table 16), while a 10-fold increase in P^{32} retention over the same soil was obtained for the 3-year cultivated muck that had received a total of 264 pounds of fertilizer P per acre. As shown in Table 16, the increase in P^{32} retention by the 3-year cultivated soil receiving 264 pounds of P per acre over the muck that had been cultivated for 3 years but had received no fertilizer P appears to be due to the difference in the amount of applied P.

It appears that the fertilizer P efficiency in

Table 15. The effect of soil cultivation and phosphorus treatment on the retention of applied P^{32} on a Houghton muck using water as the extractant.

Cultivated period Years	Total P applied Pounds per acre	Radioactivity of P^{32} in water leacheate* Counts per minute
0 (virgin)	0	5046
3	0	1202
3	264	1706
25	high rates annually	928

*Obtained by taking half the leachate (1000 ml) to dryness.

Table 16. The effect of soil cultivation and phosphorus treatment on the retention of applied P^{32} on a Houghton muck using .05 N HCl as the extractant.

Cultivated Period Years	Total P applied Pounds per acre	Radioactivity of P^{32} in .05 N HCl leachate* Counts per minute
0 (virgin)	0	24,356
3	0	3,162
3	264	2,234
25	high rates annually	900

*Obtained by taking half the leachate (1000 ml) to dryness.

muck soils would differ depending upon the extent of cultivation and previous P treatments. Accordingly, the response of crops to fertilizer P would also change.

GENERAL DISCUSSION

The method of determining organic P is based on that proposed by Mehta (55). Several steps, however, have been modified in order to adapt it to organic soils. It is still a combination of acid pretreatment and alkaline extraction.

The organic soil samples were extracted with 12 N HCl, and due to the coagulated slurry that was found at the bottom of the acid extract after standing for a few days, a comparison was made between 6 N HCl and 12 N HCl.

The following soils were extracted by the three methods indicated below:

1. Add 10 ml of 12 N HCl to 1 gm of soil and heat on hot plate for 10 minutes. Add additional 10 ml of 12 N HCl and let stand for 1 hour at room temperature.
2. Add 20 ml of 6 N HCl to 1 gm of soil and heat on steam plate for 10 minutes. Add additional 10 ml of 6 N HCl and let stand for 4 hours.
3. Add 10 ml of 6 N HCl to 1 gm of soil and heat on steam plate for 10 minutes. Add additional 20 ml of 6 N HCl and let stand for 4 hours.

The results shown in Table 17 indicate that the amount of P extracted by the three methods are in good agreement, and, 6 N HCl appeared acceptable.

In addition, the final acidity of the extract was considered. The use of 20 ml of 6 N HCl and 90 ml of 0.5 N NaOH provided an acidity that assured one hundred percent flocculation of the humus (23).

Since organic soils contain larger amounts of organic matter than mineral soils, it was necessary that the samples be treated as plant material in the perchloric acid digestion. The mixture was pretreated with 10 ml of concentrated HNO_3, and then digested with 5 ml of 72 percent perchloric acid.

In the process of P measurement, the acidified solution was brought to pH 3 which causes the formation of $Fe(OH)_3$. A small amount of citric acid, based on previous studies, was added to prevent this tendency (74, 76). Preliminary tests have shown that the addition of this organic acid will not adversely affect the results.

Many researchers believe that available forms of P can be released from organic soil compounds due to extensive microbial activities. Incubation studies were carried out, therefore, to evaluate the rate of mineralization of organic to inorganic P.

Some doubt was shed on the massive soil incubation method, which was used in a large number of previous studies. The results obtained from the small amount of incubated soil that was periodically taken from the larger amount of soil for the measurement of P. However, at least two factors had to be considered: First, if the nutrients were not well distributed through the bulk of the soil, there would be no way to insure that the smaller aliquots were homogeneous and good enough to represent the whole sample. Second, it was difficult to handle the wet soil sample and weigh it on a dry-weight basis. If the sample was air-dried, the incubation period was ultimately prolonged.

To obtain a favorable condition for the incubation of a one-gram soil sample, a 10 ml flat-bottom test tube was chosen to facilitate a 1:1 surface to volume ratio and of uniform depth. The moisture was maintained at a satisfactory level with the aid of polyethylene paper. Loss of moisture at 30°C after eight weeks only amounted to 10 percent (Table 18).

After the incubation period, the microbial activity was subdued by the addition of 10 ml of 6 N HCl. The procedure previously described was employed for the measurement of P with the following exception: the first 10 ml of 6 N HCl was heated in a water bath and alkaline extraction for the total P was omitted since there would be no change in the total P content of the soils (42).

Inorganic P measurements employing this technique were carried out in triplicate. The samples were arbitrarily numbered to prevent bias. Good reproducability was obtained (Tables 4 and 5 in Appendix).

Table 17. The evaluation of inorganic phosphorus on three Houghton muck soils by three methods.

Extraction	Parts per million P Sample 1	Sample 2	Sample 18*
10 ml 12 N HCl + 10 ml 12 N HCl	332	462	250
20 ml 6 N HCl + 10 ml 6 N HCl	310	462	304
10 ml 6 N HCl + 20 ml 6 N HCl	332	490	268

*Sample 1 = virgin (non-cultivated)
Sample 2 = virgin (cultivated)
Sample 18 = virgin (non-cultivated)

Table 18. Moisture loss from an incubated Houghton muck contained in a small test tube and covered with polyethylene paper.

	Incubation period			
	Weeks			
Moisture loss	1	2	4	8
Loss in weight (gram)	0.03	0.063	0.108	0.213
Loss in percentage	1.5	3.2	5.4	10.2

Moisture loss is the average value for weight decreases of 21 test tubes.

SUMMARY AND CONCLUSIONS

Field and laboratory investigations were carried out to correlate the response of onions and potatoes with native and applied fertilizer phosphorus, and to evaluate the importance of organic phosphorus as a source of available inorganic phosphorus to plants grown on newly reclaimed Houghton muck. The results can be summarized as follows:

1. The response of potatoes grown on a virgin Houghton muck, to applied fertilizer P was less than that of onions.
2. The depression in potato yields at high levels of applied fertilizer P may possibly be associated with a decrease in plant uptake of zinc. The potato tissue obtained from the plots receiving 88 pounds of P (200 pounds of P_2O_5 per acre) contained 33.3 percent less zinc than those obtained from the plots receiving no P.
3. Baule units of soil and fertilizer P were obtained for onions and potatoes according to the following equation:

$$\log (A-Y) = \log A - c_1 b - cx$$

1 Baule unit of soil P for onions = 4.1 pounds per acre (1963)

1 Baule unit of fertilizer P for onions = 11.9 pounds per acre (1963)

1 Baule unit of soil P for onions = 4.8 pounds per acre (1965)

1 Baule unit of fertilizer P for onions = 10.3 pounds per acre (1965)

1 Baule unit of soil P for potatoes = 2.0 pounds per acre (1963)

1 Baule unit of fertilizer P for potatoes = 18.5 pounds per acre (1963)

1 Baule unit of soil P for potatoes = 2.6 pounds per acre (1965)

1 Baule unit of fertilizer P for potatoes = 23.5 pounds per acre (1965)

4. The calculated c_1 values for onions and potatoes in 1963 and 1965 were as follows:

    Onions - .0732 and .0627, respectively.

    Potatoes - .1470 and .1170, respectively.

5. The calculated c values for onions and potatoes in 1963 and 1965 were as follows:

    Onions - .0265 and .0293, respectively.

    Potatoes - .0163 and .0128, respectively.

6. An increase in the total P content of all soils was obtained with the application of fertilizer P.

7. The inorganic P content of the virgin soil was less than the cultivated and fertilized soils.

8. The percent organic P decreased with increasing levels of fertilizer P, being highest on the virgin soil (75 percent) and lowest (50 percent) on the

soils receiving 88 pounds of P per acre for a 3-year period.

9. The incubation studies indicated that the virgin Houghton muck may be a source of P for plant growth. During the 8-week incubation period the inorganic P increased by approximately 100 parts per million.

10. There was no evidence to show that the increase in inorganic P was dependent upon the amount of applied P.

11. The studies with radioactive P indicated that the cultivated mucks retained more applied P^{32} than the virgin mucks. Water leachates from the 25-year cultivated muck revealed a 5-fold increase in P^{32} retention over the virgin soil while a 27-fold increase in retention of this element was obtained when the same soils were leached with .05 N HCl.

12. The data suggest that the efficiency of fertilizer P in muck soils would differ depending upon the extent of cultivation and P treatments. Accordingly, the response of crops to fertilizer P would also change.

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APPENDIX

Table 1. The relationship between soil treatment and Bray P_1 extractable phosphorus, 1963, 1964 and 1965.

		Onions		Potatoes	
		Pounds per acre		Pounds per acre	
Year	Treatment*	Block 1	Block 2	Block 1	Block 2
	P_o	6	11	6	11
	P_o	6	12	6	12
	P_o	7	9	7	9
1963	P_1	8	6	8	6
	P_2	11	8	11	8
	P_3	8	12	8	12
	P_4	8	14	8	14
	P_o	9	29	9	29
	P_o	6	36	6	36
	P_o	6	41	6	41
1964	P_1	10	20	10	20
	P_2	16	10	16	10
	P_3	30	11	30	11
	P_4	12	29	12	29
	P_o	9	11	10	3
	P_o	9	6	7	3
	P_o	10	3	9	4
1965	P_1	9	9	6	7
	P_2	10	6	9	3
	P_3	14	6	11	9
	P_4	30	36	27	15

*P_o, P_1, P_2, P_3 and P_4 designate 0, 11, 22, 44 and 88 pounds of phosphorus per acre, respectively.

Table 2. Yields of onions and potatoes grown on a Houghton muck, 1963, 1964 and 1965.

		Onions		Potatoes	
		Cwt. per acre		Cwt. per acre	
Year	Treatment*	Block 1	Block 2	Block 1	Block 2
	P_o	434	537	269.5	237.5
	P_o	400	546	270.5	229.3
	P_o	565	502	280.9	246.4
1963	P_1	562	517	283.2	256.2
	P_2	589	603	292.7	244.4
	P_3	557	561	296.0	236.2
	P_4	631	647	240.3	215.8
	P_o	361	348	232	237
	P_o	387	395	226	194
	P_o	458	546	229	243
1964	P_1	324	388	189	265
	P_2	364	419	252	226
	P_3	334	332	242	302
	P_4	397	356	186	192
	P_o	381	507	327	297
	P_o	311	515	221	233
	P_o	387	398	201	161
1965	P_1	590	688	288	314
	P_2	644	657	345	298
	P_3	664	637	360	350
	P_4	673	521	346	281

*P_o, P_1, P_2, P_3 and P_4 designate 0, 11, 22, 44 and 88 pounds of phosphorus per acre, respectively.

Table 3. Total, inorganic and organic phosphorus in virgin and cultivated Houghton mucks.

Treatment	Total	Inorganic	Organic
		ppm P	
Virgin	1156	293	863
No fertilizer	1413	608	805
P_o	1400	560	840
P_o	1413	928	847
P_o	1356	463	950
P_o	1400	530	939
P_o	1469	625	813
P_o	1513	528	828
P_1	1413	543	870
P_1	1400	530	870
P_2	1469	450	950
P_2	1456	860	828
P_3	1438	463	1006
P_3	1731	565	891
P_4	1775	533	980
P_4	1688	625	1106

Table 4. Inorganic phosphorus content of virgin and cultivated Houghton mucks prior to incubation.

Sample* number	ppm P added**	Inorganic P ppm
1 (V)	0	230
2 (V)	0	230
3 (V)	25	250
4 (V)	25	254
5 (V)	50	304
6 (V)	50	300
7 (V)	200	446
8 (V)	200	441
9 (V)	400	640
10 (V)	400	640
11 (C)	0	616
12 (C)	0	620
13 (C)	400	1044
14 (C)	400	1078

*"V" designates virgin muck; "C" designates cultivated muck; samples run in duplicate (e.g., 1 and 2, 3 and 4, etc.).

**300 ppm of N and 20,000 ppm of sucrose were added prior to incubation.

Table 5. Inorganic phosphorus content of virgin and cultivated Houghton mucks after 1, 2, 4, 6 and 8 weeks incubation.

Sample* number	ppm P added	Incubation period 1	2	4	6	8
		ppm P				
1 (V)	0	274	300	290	366	330
2 (V)	0	248	294	254	360	330
3 (V)	0	240	300	260	374	316
4 (V)	25	320	298	336	420	370
5 (V)	25	320	286	350	412	300
6 (V)	25	300	350	340	420	348
7 (V)	50	324	322	368	400	380
8 (V)	50	350	334	400	404	432
9 (V)	50	342	370	374	400	412
10 (V)	200	438	448	466	586	552
11 (V)	200	480	454	474	560	552
12 (V)	200	500	448	480	552	488
13 (V)	400	600	716	652	672	634
14 (V)	400	604	716	678	716	776
15 (V)	400	590	728	630	700	700
16 (C)	0	622	640	574	700	660
17 (C)	0	636	638	592	732	614
18 (C)	0	612	764	576	684	600
19 (C)	400	926	950	978	1116	1032
20 (C)	400	986	1030	1032	1150	1000
21 (C)	400	932	1026	972	1100	980

*"V" designates virgin muck; "C" designates cultivated muck. Samples run in triplicate, e.g., 1, 2, 3 or 4, 5, 6, etc.