

1936

## The effect of additions of calcium hydroxide upon the solubility of phosphorus in certain Massachusetts soils

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<https://doi.org/10.7275/6871034>

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THE EFFECT OF ADDITIONS OF  
CALCIUM HYDROXIDE UPON THE SOLUBILITY OF  
PHOSPHORUS IN CERTAIN MASSACHUSETTS SOILS

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THE EFFECT OF ADDITIONS OF CALCIUM HYDROXIDE  
UPON THE SOLUBILITY OF PHOSPHORUS IN CERTAIN MASSACHUSETTS  
SOILS.

By

John Nelson Everson

A thesis submitted as partial fulfilment of the requirements  
for the degree of Master of Science.

June 1, 1936

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## I. PURPOSE OF THE STUDY.

The solubility of phosphorus compounds in the soil is a subject of great importance in agronomy, as phosphorus is one of the three primary plant nutrients found in the soil. The common use of lime additions to the soil as an acid corrective and nutrient makes a study of the interrelations of liming and phosphate solubility worth while. From the days of Dyer's (7) discovery, at Rothamsted, that there was little or no phosphate lost from the lysimeter tanks, up to the present time, there has been conflicting evidence in the literature as to the effect of liming upon the solubility of phosphates. While no direct reference is made at this time to the work of Bear and Salter (3), Sewell and Latschaw (21), Gaarder (10), Wheeler (25), Ames and Schollenberger (1) Gile and Cerrero (11), or Midgeley (17, 18), a general statement may sum up the situation. Some authors give evidence that liming under certain conditions decreases the solubility of phosphorus compounds, while others claim that in some cases the phosphorus found in plant tissue is higher in plants grown in limed soil than in those grown in unlimed soil. It is recognized that the addition of lime to a soil could increase the phosphorus intake of a plant, due to the establishment of conditions more favorable to plant growth. The question as to whether the addition of lime



actually increases or decreases the solubility of phosphorus compounds in the soil seems to find no agreement among the workers. The work reported here is an attempt to determine the solubility of phosphorus compounds as effected by the addition of calcium hydroxide in water solution. A study is first made of the relations between calcium hydroxide additions and pH of the soil. This is purely incidental to the main study of relations of phosphorus solubility and pH of the soils, as raised by the addition of calcium hydroxide.

The scope of this study is limited to the effect of additions of calcium hydroxide in water solution upon the solubility of phosphorus found in the soil as received, and the solubility of this phosphorus at the consequent higher pH values. The main study is confined to the pH range most favorable to greatest plant growth, beginning at the pH at which the soils were received and ending at pH 7. In many soils results were given at higher pH values but no attempt was made to relate them in any way.

## II. PROCEDURE FOLLOWED.

The general procedure followed in this work was the selection of a group of soils which would represent the range of soil types found in Massachusetts, the preparation of those samples in such a way that the actual soil conditions would be changed as little as possible, and the treatment of each soil chosen with amounts of calcium hydroxide which would create definite pH values. The solubility of the phosphorus was then determined over a pH range beginning at the natural pH and ending at pH 7. The percentage of clay was determined by the Bouyoucos method. The first part of this paper is devoted to the sources of samples, their preparation, and the methods used.

### A. Sources of Samples.

1. Series studied--Massachusetts soils are very varied in type not only in the state as a whole but even within small areas. An attempt has been made in the selection of the soils used to choose those which would represent the origins of the more common series. The oldest series of the state are glacial in origin. Gloucester, Merrimac, and Carver were selected as representatives of the glacial series. The youngest soils of the state are alluvial. Agawam is an older alluvial and Hadley one of the youngest alluvials. The five series chosen then represent one of the oldest, Gloucester; three series of intermediate age, Merrimac, Carver, and Agawam; and one of the youngest, Hadley. A brief description is given of each series.

a - Gloucester Series--The Gloucester series (15) are glacial till soils. They are the most widespread soils of the highland east of the Connecticut river. The "A horizon" consists of a somewhat granular, dark brown, fine sandy or light loam. Gloucester loam is a typical example of a brown forest soil developed from granitic material which has reached a mature stage. Under grass sod conditions the single grain structure is most noticeable. The surface relief ranges from gentle undulating to rolling, and the drainage is well established. The entire profile contains some granitic rock fragments and boulders, making the soils difficult to cultivate by machine.

b - Merrimac Series--The Merrimac series (15) of soils has developed in the higher terraces of the river valleys of Massachusetts. These soils are not of river origin but are soils of the older glacial terraces. In the Connecticut Valley region the series was derived from Triassic sandstone, while in the eastern part of the state the series were of granitic origin. Many soils of the series have gravelly surfaces, but not enough gravel is present to form a surface mulch. The profile is well developed, indicating an older soil. The soils are well drained, and in some cases overdrained.

c - Carver Series--The Carver series (15) are glacial terrace soils located in the southeastern part of the state and in the islands. These soils are found south



and east of granitic terminal moraines. Their topography is from fairly level to slightly rolling. The profiles are well developed and the drainage is well established. Many of the island soils of this series are covered with scrub oak growth. Some of the market-garden soils of the Brockton, and Halifax areas are of this series and are reported to be of good fertility. The series are largely of granitic origin.

d - Agawam Series--The Agawam series (15) were formed on the higher river terraces. They are above normal flood level. In Franklin, Hampshire, and Hampden counties these are very important agricultural soils. These are old alluvial soils in which the profiles are poorly developed, but better than the Hadleys. These soils are brown and are intermediate, both in location and in general qualities between the Hadley alluvials and the Merrimac Triassic soils.

e - Hadley Series--The dominating series of the present Connecticut river valley are Hadley (15) and Agawam. The Hadley series are located in the lower river terraces. They are of alluvial origin and, as they are in the overflow basin, are still in the process of formation. The surface relief is from fairly level to gently sloping, and is characterized by a series of gentle swells that paralleled the current at the time the deposits were laid down. This series of soils are the best both in easy tillability and in

agricultural production in Massachusetts and are one of the most important in the eastern part of the United States.

2. Why chosen--The five series taken for study not only represent soils of varying geological origin and different stages of maturity but they also typify series varying from the roughest to the smoothest agricultural soils.

Soil samples have been taken by the extension service and, when completed, the collection will represent all of the soil series and each texture of each series found in the several counties of the state. It was from this set of soil samples that the soils used in these tests were taken. The samples, then, being taken in different parts of the state, may be considered more representative of state soil conditions than if all of the soils of a given series had been taken within a more limited area. These acid soils were taken from uncultivated fields which had not been recently fertilized. A list of towns from which samples were taken is given in table 1.

### B. Preparation of Samples.

Upon receipt in the laboratory, the samples were spread to air dry, rolled with a wooden roller, and passed through a two-millimeter sieve. The samples were then stored in stoppered glass bottles from October and November of 1934 until January of 1935, when the work of testing was begun. All of the determinations were made upon samples screened through the two-millimeter sieve, as samples screened through one-millimeter would not properly represent the field condition of the coarser soils of the series. Sieving through a one-millimeter sieve would have left some of the coarser soils classifying as fine sandy loams rather than coarse sandy loams. In order to overcome the separation of coarse and fine particles, through sliding off the spatula, the thinly spread samples were sub-sampled, by the use of a rounded tipped spatula.

### C. Methods Used.

Uniform standards of procedure were used throughout the tests. In weighing, whether for pH determination, lime requirement, phosphorus solubility, or clay determination, the samples were always spread and sampled in the manner stated. In the description of the various procedures used, more emphasis is given to the determination of pH values and to the method of determining lime requirement than is given to the method of determining phosphorus solubility, because the success of the



work depended, absolutely, upon the exact reproduction of pH conditions and lime requirement conditions, while the procedure in determining phosphorus was the standardized method of Truog (22).

1. Determination of the pH Value of the Soil Suspension--Truly speaking, the pH value of a soil is never determined. The nearest approach to soil pH value is the determination of that value in the soil solution. In this work the value which is called soil pH is the pH of the soil suspension under very definite conditions. In giving pH values of soils it is necessary to state the exact conditions under which the tests were made. In this work the concentrations were kept uniform, so that little variation in dissociation would be caused. In this work the quinhydrone method of the International Soil Society (Moscow meeting) was followed, except that the contact time between the soil and water was lengthened to fifteen minutes.

The Method--Ten grams of soil were placed in a fifty milliliter beaker and exactly twenty-five milliliters of cooled reboiled distilled water were added. After stirring intermittently for fifteen minutes, approximately 0.1 gram of quinhydrone was added and the suspension was stirred for one minute. At the end of this time the reading was made using a Leeds Northrup potentiometer. The indicated pH was corrected by making the  $pK_w$  temperature

correction. In order to overcome the sorption effect of potassium chloride and the consequent drift in potential, a bridge was used made from two percent agar in saturated potassium chloride. As a matter of safety, the saturated potassium chloride--calomel half-cell was flushed after being used four or five times.

It was found in preliminary tests of air-dried soils that there was a serious drift in potentiometric readings if only five minutes contact was allowed between soil and water. At the end of fifteen-minutes contact practically no such drift was observed.

2. Determination of lime requirement--Lime requirement, as the term is employed here, is the amount of calcium oxide required to raise one million pounds of soil from its natural pH to a pH value of 7. The definition is limited in another respect. It is to be understood that when the soil is held in damp condition for one week it must retain its pH value of 7. This limitation made the work quite tedious as a large amount of time was expended upon some soils before they reached an equilibrium which would hold for one week. The time was well expended as the lime requirement values established were reproducible. As the primary object of this work was to determine the effect of additions of calcium hydroxide upon the relative solubility of the natural phosphorus compounds, consideration was given to several methods before one was chosen



as the standard method. A short review of these methods is given.

a - In 1915 Jones (14) proposed a calcium-acetate method of determining lime requirement. In this laboratory it was observed that, after the acetate treatment, the pH value of the soil was always greater than 7. It was thought that, due to the presence of the acetate ion and the difference in its dissociation constant from that of the soil acids, the method was objectionable. In 1915 hydrogen ion concentration was not as well known as it is today. Jones method has been studied by Bayer (2), Metzger (16), and others. These workers also found that when the Jones method is used the soil is raised to a pH value higher than 7. Recognizing this fact Dean and Magistad (6) proposed that 1500 milliliters of 0.5 normal calcium acetate having a pH value of 6.5 be leached through twenty grams of soil at the rate of fifteen drops per minute. Under these conditions, using Hawaiian pineapple soils, these workers found that the final pH value of the soil after it was washed was approximately pH 7. The extract was boiled to rid it of carbon dioxide, and was titrated with calcium hydroxide until the final pH was 6.50. A few trials indicate the value of this method on Massachusetts soils. The method was not used in this work largely because of the volume of solution required, and the lack of enough percolation equipment.

a - Hissink (13) and Pari (19) advocated shaking a soil with barium hydroxide, filtering through a Buchner filter, adding an excess of acid to the filtrate and back titrating. In using these methods, Dean and Magistad (6) found that after this treatment the soil pH was 9.23 to 10.22. These methods may be considered as measures of replaceable hydrogen but they do not meet the requirement that the final soil pH must be 7. There is also the objection that the ionization constant of barium is not the same as that of calcium.

a - A procedure was tried in which the soil was suspended in 0.2 normal potassium chloride, and titrated with calcium hydroxide until the suspension showed a pH value of 7. After shaking the suspension for one-half hour a pH equilibrium was not reached. It was possible to titrate the suspension to pH 7, using the potentiometric method, but the pH usually dropped back to approximately 6.5 at the end of twenty-four hours. The phosphorus soluble in Truog extractant was higher when both potassium chloride and calcium hydroxide were added than when the same amount of calcium hydroxide was used alone. The results indicated (table 2) that the presence of potassium chloride had an effect of its own upon the solubility of phosphates, and was consequently a source of error in determining lime requirement.



Table 2                      Phosphorus soluble at pH 7		
Soil	KCl -Ca(OH) <sub>2</sub>	Ca(OH) <sub>2</sub>
189	68	44
190	58	36
191	104	52
192	98	52

b - The method used in this work was one in which there could be little introduction of disturbing factors. All of the soils were treated by the simple addition of calcium hydroxide in water solution. The calcium hydroxide, of chemical grade, was calcined and dissolved in recently boiled distilled water. This solution was kept under a mineral oil seal and the alkalinity was checked by titrating against 0.02 acid. Twenty grams of the soil were wet with distilled water, calcium hydroxide was added in small amounts, and the suspension was shaken in a stoppered bottle. Readings of the pH values were taken at intervals until a pH equilibrium was attained. More calcium hydroxide was added, and the soil was reshaken until the pH remained constant. The process was continued until the soil suspension was pH 7. In the titration of sands the pH equilibrium was usually stable in a short time. In the titration of soils of fine texture it was necessary to continue the small additions of calcium hydroxide and the shaking for long periods. In some soils daily additions of calcium hydroxide were made for one month before the equilibrium remained constant at pH 7.

In order to test the reliability of the method new samples were weighed out, and amounts of calcium hydroxide which represented the total calcium hydroxide added in the slower method were made in a single addition. After the addition of calcium hydroxide one set of samples were dried at a temperature of  $65^{\circ}\text{C}.$ , and a second set at room temperature. Those samples dried at room temperature were in some cases at higher pH values than was expected. Those samples had developed ammonium. Those samples which were dried at  $65^{\circ}\text{C}.$ , were always nearly at pH 7. The method of drying at  $65^{\circ}\text{C}.$ , was adopted as this temperature inhibited the bacterial growth which produced ammonia. Drying at  $65^{\circ}\text{C}.$ , was adopted as standard. All of the soils were dried after calcium hydroxide additions, held damp for one week, and the pH value determined with a soil-water ratio of 1 : 2.5. A few soils were held for three months. At the end of this period the pH changes were negligible.

The method of determining lime requirement is, then, as follows: 20 grams of soil were wet with distilled water; calcium hydroxide solution was added and the sample shaken until pH equilibrium was attained; more calcium hydroxide solution was added and the sample was again shaken to equilibrium; the process was continued until the pH value was 7. The water-soil ratio was reduced to 2.5 : 1 previous to each potentiometric reading. The samples were held for one week, if no lowering of pH value was noted before that time. If a pH drop did occur the process was repeated until the pH held at a value of 7 for one week. All these samples con-



tained quinhydrone and were discarded for phosphorus solubility work.

c - In reporting the results of the lime requirement tests two results are shown in tables 3, 4, and 5. One column states the number of pounds of calcium oxide required to convert 1,000,000 pounds of soil from the natural pH to pH 7. This value is shown as "CaO". The other states the amount needed to raise a like amount of soil one pH unit. This value is shown as the division,  $\frac{\text{CaO}}{7-\text{pH}}$ . This figure may be considered as a measure of the buffer capacity of the soil.

3. Determination of phosphorus solubility--Determination of the lime requirements of the various soils, although it was an essential step, was incidental to the objective, which was a study of the effects of calcium hydroxide additions upon the solubility of phosphorus. The accuracy of the phosphorus solubility tests is dependent upon the method of adding calcium hydroxide, so that in describing the determination of the phosphorus solubility procedure, references must be made to the methods followed in the introduction of calcium hydroxide as a means of regulating soil dispersion pH values. Additions of calcium hydroxide were made in such amounts that the soil suspensions were approximately 6.0, 6.5, and 7.0 in pH value. The solubility of the phosphorus by the Truog (22) method was determined at the pH of the soil as received, and at approximately pH 6.0, 6.5, and 7.0

a - The Truog method is not described, as it is a well known "phosphorus availability" procedure. Throughout this work the blue color held very reasonably true to that of the standard. In order to test the buffering of the Truog extracting solution, to determine whether or not there was a marked change in its pH value before and after extracting a soil, the pH values were checked after extracting some soils varying in pH value. These pH values are shown in table 9. The results show a maximum range of from pH 2.9 to 3.4, or a gross variation of 0.50 pH units. This shows that the extracting solution was well buffered.

Table 9                      pH values of soil extract.		
Soil	Soil pH	Extractant pH
165	5.15	2.95
165	7.00	3.25
171	5.05	2.95
171	7.00	3.40
179	5.10	2.90
179	7.55	3.35

In setting the pH of the soils at the value of 7, the method was to add to each soil an amount of calcium hydroxide which had previously been found necessary in determining lime requirement. The amounts of lime required to convert the soils to the pH values of 6.0 and 6.5 were not determined directly but were calculated from the assumption that, when changes in pH value from the natural pH value to pH 7 were plotted against the



amounts of calcium hydroxide necessary to convert the soil suspension from the natural pH value to pH 7, a straight line graph would result. This was not a strictly valid assumption, due to the fact that perfectly straight line titration curves exist only in the middle part of well buffered solutions. Assuming that the straight line condition did exist, the theoretical amounts of calcium hydroxide necessary to raise each soil from its natural pH value to pH values of approximately 6.0 and 6.5 were interpolated by dividing the lime requirement by the unit change between pH 7 and the natural pH value and multiplication by the unit change desired. These amounts of calcium hydroxide were added to the soils. In tables 6, 7, and 8, it is seen that the assumption must have been nearly correct in some cases, as in soils 180 and 215; while in the majority of the soils the straight line condition was approximate.

Calcium hydroxide, in the same water solution as previously used, was checked by titration against 0.02 normal acid, and the appropriate amount was added to each soil. The soils were dried at 65°C., remoistened and held damp for one month. This period was three weeks longer than that with the soils held for lime requirement, and the time may have been unnecessarily long, but it seemed desirable to allow ample time for the establishment of equilibrium between the soil and the added calcium hydroxide. At the end of four weeks the soils were dried and

the soluble phosphorus was determined by the Truog method. Results with soils held for twelve weeks did not vary significantly from those at the end of four weeks, consequently the four week holding period was adopted. After the soluble phosphorus was determined the pH values of the soils were determined. The results of the phosphorus determinations are shown in the third, fifth, and seventh columns in tables 6, 7, and 8.

The phosphorus results shown in these tables are the averages of two or more determinations. In making these determinations a method was used which held the pH value practically constant. In each instance the same number of milliliters of calcium hydroxide were added to each pair of soils making it possible to avoid variations in pH value.

4. Bouyoucos clay determinations--The percentages of clay were determined by means of the Bouyoucos (4) hydrometer method. It is admitted that this method is subject to error in the presence of large amounts of organic matter. In the majority of these soils, however, the organic matter was very low. In one sample, the clay by this method, was so high that it would seem that the soil should take a different position in the solubility ratio table later referred to. In this one case the Bouyoucos suspension was decanted, evaporated, washed, and ignited. The washing was necessary to remove sodium hydroxide and sodium oxalate which were added in the Bouyoucos method.



### III. INTERPRETATION OF RESULTS.

As there were fifty-eight soils tested and the pH values were determined at the natural pH, at pH 6.0, 6.5, 7.0, and at one other value, and as these tests were made in duplicate, the number of direct pH values was at least five hundred eighty. It is impossible to even roughly estimate the number of tests for pH which were made in raising the pH values to 7 during the process of calcium hydroxide addition. More than six hundred solubility (Truog) tests were made and the clay was determined 117 times. The results reported are average values. The basis of reporting was upon air-dried soil weight.

#### A. Effects of Liming.

The primary purpose of this work was to relate the pH values of soils when raised by the addition of calcium hydroxide to the phosphorus soluble at the higher pH values, but it seems well to include a statement as to some of the peculiarities noted during the titration with calcium hydroxide, and a brief statement of some of the lime relations among the different series.

There were some peculiarities shown by certain soils on the addition of calcium hydroxide. A general statement may be made that when calcium hydroxide was added to a soil of coarser texture, under the conditions of these tests, the reaction between the hydrogen ions of the soil and the calcium hydroxide required a very short time. It was almost possible, in some of the sandy or coarse sandy soils, to titrate them directly from their

natural pH to a pH value of 7. After each calcium hydroxide addition a brief shaking brought these soils to pH stability. The greatest difficulty encountered in titrating these soils was the danger of over-titrating them, since when the pH value was carried slightly beyond pH 7 these soils did not show much pH drop. The indication in such cases was that a condition very like simple acid-base titration was approached. Samples 111, 112, and 176 showed this simplicity of titration to a marked degree. By way of contrast, samples 126, 127, 194, and 200 showed marked differences in titration characteristics. From the beginning to the end of the titration of these soils there was a retardation in reaction time. In the earlier stages of the titration these soils reacted quite rapidly; that is, after shaking a short time they reached pH stability. With later calcium hydroxide additions there was a slowing down of the reaction between the soils and the calcium hydroxide. After being raised to pH 6.5, the subsequent addition of a small amount of calcium hydroxide raised these soils to a temporary pH value of 7. This pH value dropped slowly until it approached 6.5, but with each addition of calcium hydroxide the subsequent drop in pH was less. These soils required much careful titration and many pH checks before they were finally stable at pH 7. As an explanation of the phenomenon of slow reaction time it may well be assumed that the



changes which took place slowly were not simple ones such as acid-base titrations, but were changes within the complexes. This seems to be evidenced by the changes in the solubility of phosphates shown in the pH ranges from 6.5 to 7.0. A remarkable fact, in this connection, was that when the lime requirement had finally been determined, and the addition of the required amount of calcium hydroxide had been made to the soils, they became adjusted to a pH equilibrium at 7 in one week's time.

#### B. Results Related.

With the exceptions of pairs of soils 142 and 143, 175 and 176, and 203 and 204, the top-soils showed higher lime requirements per unit of pH change than did the sub-soils. In tables 10 and 11 the Gloucester and Merrimac soils are placed in the order of their lime requirements per unit change in pH value. In these tables it will be noticed that, as a whole, the amounts of lime required per unit change in pH value is much higher in the Gloucester series than it is in the Merrimac series. Not enough samples of the Carver, Agawan, or Hadley series were tested to allow any lime relations to be deduced.

1. Related to original soluble phosphorus--An examination of the data in table 6 shows that in the Gloucester series tests, sample 176 showed a loss in solubility of 3 pounds in 2,000,000 pounds of soil. This soil was the only one of the Gloucester series

which showed any loss in phosphorus solubility when the pH of the soil suspension had been raised to pH 7 by the use of calcium hydroxide. In those soils which showed comparatively the same amounts of soluble phosphorus, about 40 pounds per acre at the natural pH value, sample 85 which had originally 40 pounds increased to 53 pounds; sample 175, originally 36 pounds, increased to 60 pounds; sample 193, originally 48 pounds, increased to 72 pounds; sample 194, originally 48 pounds, increased to 119 pounds; sample 195, originally 44 pounds, increased to 58 pounds; sample 196, originally 45 pounds, increased to 68 pounds; sample 201, originally 43 pounds, increased to 68 pounds; sample 215, originally 49 pounds, increased to 58 pounds; sample 216, originally 49 pounds, increased to 62 pounds; sample 223, originally 48 pounds, increased to 70 pounds; and sample 224, originally 48 pounds, increased to 70 pounds. In this series of soils of approximately the same original (Truog) soluble phosphorus content, there was an extreme variation in pounds gained of from 9 pounds in the case of soil 215, to 71 pounds in the case of soil 194.

In the Merrimac series, (table 7) a condition, very similar but more marked, existed. Samples 111, 112, 142, 143, 165 and 166 all showed losses in solubility of phosphorus after the pH had been raised to pH 7. In those soils, having originally from 40 to 50 pounds of soluble phosphorus, soil number 75 with 49 pounds of original soluble phosphorus increased to 65 pounds at pH 7;

similarly, soil 54 increased from 43 to 44 pounds; soil 75 increased from 49 pounds to 65 pounds; soil 76 increased from 40 pounds to 44 pounds; soil 80 increased from 39 pounds to 40 pounds; soil 171 increased from 42 pounds to 45 pounds; and soil 172 remained stationary at 42 pounds. The evidence here showed that in soils of approximately the same original phosphorus solubility, there were great differences in increase in the solubility when the pH value was raised to pH 7 by calcium hydroxide. It seems only logical to conclude, then, that there is no relationship between the amount of phosphorus originally soluble and that soluble at pH 7. Pounds increase of soluble phosphorus seems worthless as a direct basis of comparison of phosphorus solubility with pH change. As will be shown, subsequently, there is an indirect relationship, but before establishing it other values are considered.

2. Related to pH--All of the soils were acid soils. In the Gloucester soils 194, 199, and 200 the pH values (table 6) were respectively 4.75, 4.40, and 5.30. All of these soils showed increases in phosphorus solubility. Soil 176, which showed a loss in solubility on raising the pH to a value of 7, had a pH value of 5.10. This soil came within the same pH range as those soils which showed increases. In the Merrimac series soils 126, 127, 134, and 204 showed increases in phosphorus solubility. The pH



values (table 7) of these soils were respectively 5.00, 5.30, 5.20, and 5.70. Soils 111, 112, 142, 143, 165, and 166 all showed slight or large losses in phosphorus solubility when the pH was raised to 7. The pH values of these soils were respectively 5.25, 5.40, 6.10, 6.65, 5.15, and 5.30. It was shown that those soils showing increases and decreases in phosphorus solubility did not come within a definite original pH range. It may be deduced that in these results no relationship was shown between the original soil pH value and the increase or decrease in phosphorus solubility, when calcium hydroxide was added in quantities sufficient to raise the pH to the value of 7.

3. Relation to origin--As these soils were of various origins, glacial till, glacial terrace, older and younger alluvial, and as changes in solubility occur in all of the series it may be assumed that there was no relationship between the origin of the soil series and the increase in solubility of phosphorus when the pH is raised to the value of 7.

4. Relation to organic matter--As one half of these soils were top-soils and the other half sub-soils, and as the top-soils contained more organic matter than did the sub-soils, the fact that the top-soils and sub-soils were distributed in their solubility response to pH indicated that there was no relationship between their organic matter and the solubility response.

5. Related to texture--Having eliminated the possibilities of relationships between the increased soluble phosphorus found at pH 7 and original phosphorus solubility, original pH value, soil origin, or organic matter content, the possibility was considered that soil texture could be the controlling factor, or that some complex related to texture could be involved. Upon consideration of the possibility that both texture and definite compounds or complexes were involved, it seemed possible that the original phosphorus solubility and the solubility at pH 7 could be related to these factors. If this were the case, the ratios secured by dividing the phosphorus soluble at pH 7 by that soluble at the original soil pH should establish a relationship between increase in phosphorus solubility and texture or per cent of the complex. It was found that when this series of divisions were made and the ratios established, there was a wide range of ratios, from positive solubility responses in such ratios as 1 : 2.35 or 1 : 2.50 down to negative responses as great as 1 : 0.71. The soils of each series were placed in the order of their ratios of solubility response, beginning with the highest positive response and ending with the negative responses. After the soils had been placed in this order, the soil textures were written in. A general conclusion may be drawn from the data found in tables 12, 13, and 14: those soils having the highest ratio of increase in

soluble phosphorus at pH 7 over that at the natural pH were soils of finer texture, while those showing negative solubility response, or decrease in solubility, were of very coarse texture. It was concluded that there was a decided relationship between soil-texture and solubility response to lime additions.

A closer examination of the Gloucester series (table 12) showed that very fine sandy loams head the list. These were followed by 9 fine sandy loams, with an exception interspersed between the fifth and sixth fine sandy loams. This soil was a sandy loam seemingly out of order. Following the fine sandy loams were three sandy loams. The next sample, 215, was to appearance a silt loam. With the exceptions of samples 197 and 215, the soils followed a decided relationship between texture and ratio response.

In the Merrimac series (table 13) the relationships were not so well established. The first six soils were very fine sandy loams; these were followed in order by two loamy sands, four sandy loams, a fine sandy loam, two sandy loams, a coarse sandy loam, a sandy loam, two loamy sands, two sandy loams, and finally three loamy sands. At the first examination of this table it seemed that the relationship between texture and phosphorus solubility response was, at best, limited to the upper part of the table. A closer examination of this table



revealed that in many of the results shown for phosphorus solubilities at the natural pH (column P) and the solubilities at pH 7 (column P a pH 7) the increases and losses were so slight, in pounds, that the changes were within the limits of error of the Truog method. Even though the Duboscq colorimeter was used, the multiplication by four caused an error of four pounds, when the error of reading was one pound. When this fact was considered, it seemed possible that due to the errors in reading and the multiplication of those errors some of the soils were placed out of their proper ratio response position and so did not follow the texture order. This error was more significant in those soils which changed very little in phosphorus solubility. Those soils in the Merrimac series which were badly misplaced in texture order may have been so placed because of error in the Truog method.

In general it may be said that there was a positive response, or increase in phosphorus solubility in the fine textured soils, and a negative response in the coarser soils when the pH of these soils was raised to pH 7 by the addition of calcium hydroxide. This general condition was shown by grouping the solubility response ratios for each series with the soil textures in table 15. This grouping showed that in the series tested the proportionate increase in solubility of phosphorus at pH 7 over that at the natural pH is related to texture. The exceptions, which were so outstanding, called for explanation.

6. Clay phosphorus relations--As a general rule, the finer the soil texture, the larger the amount of clay in the soil. This general fact leads to the determination of the clay in each soil by the Bouyoucos (4) method. These clay values were placed in tables 12, 13 and 14. The first outstanding fact was that there was a general trend of high clay content in the more finely textured soils and a lowering of the clay content in the coarser soils. A closer inspection of the clay percentages showed some results which appeared inconsistent to the apparent texture. In table 12 sample 215 was listed as a silt loam. The small amount of clay present, 1 per cent, indicated that this soil was a silty sand. Those soils which exhibited a decrease in the solubility at pH 7, with the exception of soil 142, had very low clay percentages.

In the Gloucester series it was apparent that samples 194 and 200, which showed ratios of phosphorus soluble at the natural pH to that soluble at pH 7 of 1:2.49 and 1:2.50 respectively, the clay percentage was 10. Samples 199 and 202 had 8 per cent clay. Their ratios of phosphorus soluble at the natural pH to that soluble at pH 7 were 1:1.93 and 1:1.79 respectively. In the group having 7 per cent clay, samples 175, 101, 195, and 193 showed a steady regression varying from 1:1.66 to 1:1.50 in phosphorus solubility ratios at the natural pH compared to those at pH 7. Soil 196 fell within this

solubility ratio, but had a clay content of only 6 per cent. The 6 per cent clay series soils, 196, 224, 223, 197, and 195, still showed lower ratios than soils which contained 10, 8, or 7 per cent of clay. The apparent exceptions, soils 179 and 193, are top soils and the discrepancies may be the result of errors which are known to occur in the presence of organic matter in the Bouyoucos method. Those soils having 5 per cent of clay showed the same general depressions of phosphorus solubility ratios below soils having larger amounts of clay. The soils having 1 and 2 per cent clay showed very little increase, or even some decrease in phosphorus solubility at pH 7.

In the Merrimac series the relationships were not so consistent as in the Gloucester series. There was the same general trend, the soils high in clay showing the greatest increases in ratios of phosphorus soluble at the natural pH to that soluble at pH 7. The greatest inconsistencies in the placement of soils (table 13) on the basis of per cent clay were, as with texture placements, with those soils showing very small differences in pounds-per-acre increase of soluble phosphorus. Sample 206 showed only 4 pounds increase at pH 7, while 171 showed only 2 pounds increase, and 53 showed only 2 pounds increase. Samples 54, 172, 76, 166, 142 and 143, all showed very small differences between phosphorus soluble at the natural pH and that soluble at pH 7.



In such cases it was assumed that, due to errors in the Truog method, the results on these phosphorus determinations may be considered as the cause of the irregularity of the relations between phosphorus solubility ratios and the percentages of clay. In the case of soil 142, which had an organic matter content of 9.5 per cent, the 6 per cent clay shown for this soil is in error. A determination of clay by dispersion, decantation, evaporation and ignition gave a clay content of 1 per cent on soil 142.

In table 14, the Agawam, Carver, and Hadley series, the ratios of phosphorus soluble at the natural pH to that soluble at pH 7 agreed well in clay content with soils of similar content in the Gloucester and Merrimac soil series.

It would seem that there is a relationship between the percentage of clay in an acid soil and the increase in the solubility of its phosphorus when the pH is increased by the use of calcium hydroxide. In order to confirm this opinion, a correlation was made by the method used by the Department of Education. This method, using all the soils tested, gave a correlation of  $0.82 \pm 0.05$  between percentage of clay and the ratio obtained by dividing the phosphorus soluble at pH 7 by that soluble at the natural pH. As this method is not exact, due to the fact that each result is not calculated at its exact value but with a group numerically near it, the correlation was recalculated by the method used by Wallace

and Snedecor (23). The correlation between percentage of clay and the ratio secured by dividing the phosphorus soluble at pH 7 by that soluble at the natural pH was  $0.85 \pm 0.02$ .

Soils are mixtures of chemical compounds. Soils taken over a considerable area, such as the one from which these soil samples were taken, must show considerable variation in the amounts of various salts and complexes present. These soils were variable in their active acidity, as shown by pH values, and in their total acidity, as shown by their lime requirements. The fact that there was a relationship established by correlation between the clay content and the ratio of increase in phosphorus solubility at pH 7 over that at the natural pH value may be considered as evidence that in acid soils phosphorus is combined in the clay.

C. A re-examination of the tests of the Gloucester, Merrimac, Carver, Agawam, and Hadley soils in tables 6, 7, and 8 showed some general phosphate solubility pH relations:

In the range beginning at the natural soil dispersion pH, the addition of calcium hydroxide in amounts capable of raising the pH to 6 had no effect, or a slightly depressing effect, upon the phosphorus solubility. Upon the addition of calcium hydroxide in amounts that raised the pH to 6.5 some soils showed an increase in phosphorus solubility, while others showed

no such effect. In those soils which showed a slight increase in phosphorus solubility at pH 6.5, the addition of amounts of calcium hydroxide necessary to raise the pH to 7 resulted in a marked increase in phosphorus solubility. In those soils showing no increase at pH 6.5, there was no increase in solubility at pH 7. Those soils which showed an increase in phosphorus solubility at pH values of 6.5 and 7 contained larger percentages of clay than did those soils which showed no increases in phosphorus solubility in the same pH range.



#### IV. RESULTS RELATED TO THE LITERATURE.

After this work had reached the stage which pointed strongly to a relationship between the percentage of clay in a soil and the increase or decrease in the solubility of the phosphorus when the pH was raised to 7, a search of the literature revealed some material which may be considered as evidence, if not as proof.

##### A. The Work of Ford.

In his work with De Kalb, Tilsit and other silt loams, Ford (9) found increases in available phosphoric acid in the soils after they had been limed. This was attributed to the fact that manure was used on the check plots. As the phosphorus in manure is very low these results may be explained as being due to the effect of lime in increasing the phosphorus solubility. If all of the credit for increase in phosphorus solubility were given to the use of lime, the ratios of increase would be 1 : 2.75, 1 : 1.94, 1 : 1.71, and 1 : 1.27. Stated in this manner the results are somewhat in line with those reported here. No pH conditions were reported in the article.

The same article showed that in these plots where no super-phosphate was applied, and in the super-phosphate plots, the greater part of the phosphorus was present in the clay separates. In the fine sand separates he found 27.66 and 24.36 pounds of total phosphorus per acre. In the fine clay he found 556.22 and 609.11 pounds

per acre. These results were quite significant as the fine sand separates were 15.36 and 15.23 per cent while the fine clay fractions were only slightly greater, 18.16 and 19.13 per cent. This may be taken as evidence that the clays had a greater fixing power for phosphates.

#### B. The Work of Scarseth.

Scarseth (20) following the work of Brown and Byers (5) and that of Gaarder (10) worked upon the aluminosilicate complexes derived from Bentonite. He found that in the presence of sodium sorption no fixation of phosphates took place in the electro-dialized clay. This was attributed to the saturation of the clay by sodium sorption. When mono-calcium phosphate was added to the dialized clay he found sorption of phosphates. When iron was higher in the complex a greater fixation of phosphates was observed than when iron was extremely low. The fact of no fixation when the clay had sorbed sodium was attributed to the monovalent condition of sodium. When divalent calcium was added as in the addition of mono-calcium phosphate, calcium replaced hydrogen and the second bond united through oxygen to the phosphorus group. This worker also found that OH and  $\text{SiO}_2$  ions could replace the phosphate ions. No statement was given of the pH values at which the exchange took place. Scarseth's formulation is shown in figure 1.

### C. The Work of Midgeley.

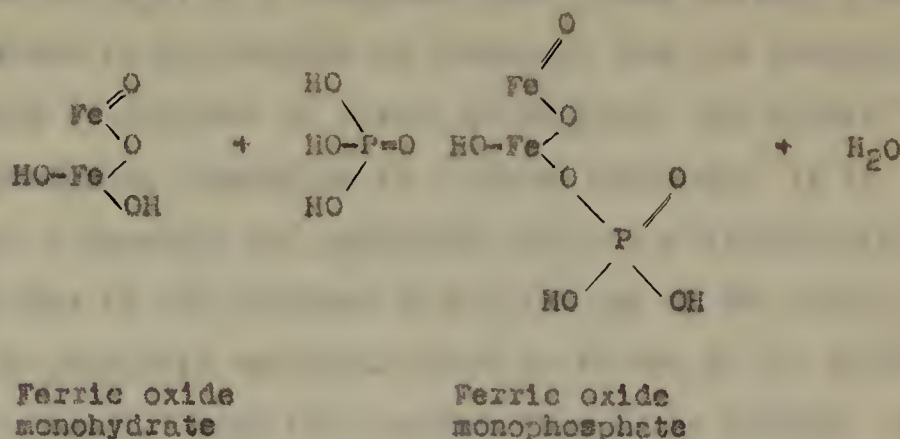
Midgeley (17) (18) found that the addition of silicates to an overlimed soil overcame the effect of overliming. This may be considered as evidence that the silicate anion had replaced fixed phosphates and released them for plant use.

### D. The Older Theory.

In the older studies of soil phosphates it was assumed that phosphorus combined in simple relations. In the work of Heck (12) a review was given of the older phosphate fixation theory. In this review it was assumed that calcium, iron, and aluminum were involved in this fixation. It is stated that dehydrated iron oxide (hematite) does not react with soluble phosphates, but that ferric oxide monohydrate (Goethite) is very reactive, forming ferric oxide monophosphate (dufrenite). The formulation is shown in figure 2. Similar formulations were given for diferric oxide and triferric oxide monophosphates. A theoretical assumption was also made that aluminum forms salts analogous to the iron compounds. With calcium it was assumed that the usual mono-, di-, or calcium phosphate were formed. In referring to the work of Gaarder (10), Heck reported that at pH 6.5 the amount of phosphorus going into solution from calcium phosphate is about one-third that going into solution from aluminum phosphate, and only about one-fourth that



Figure 2 Reaction of ferric oxide monohydrate with phosphoric acid.



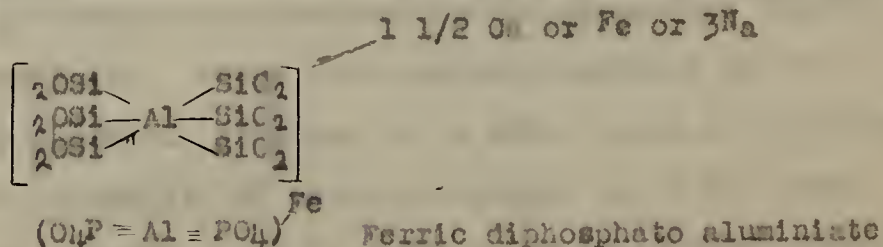
going into solution from iron phosphate. At pH 5.5 he reported that the solubility of calcium phosphate is 3 to 5 times that of iron or aluminum phosphate. This is evidence that the phenomenon of increased phosphate solubility found at pH 7 in this work is not due to increased calcium phosphate solubility. It would seem difficult to explain the increased solubility at pH 7 if iron or aluminum phosphates were involved.

#### E. The Werner Complex.

In considering the modern theory, the possibilities of the Werner (24) complexes may be considered. In this theory it is postulated that silica complexes are formed about aluminum, six silica oxides or three silicate ions satisfying the aluminum charges. The three outer charges are the satisfied by bases. Such a

condition is shown in figure 3. In this concept it is assumed that the silicon oxide groups may be exchanged with  $\text{OH}^-$ ,  $\text{H}_2\text{O}$ , or a phosphate ion. Under certain conditions it is possible to postulate that the phosphorus could be replaced by silica or  $\text{OH}^-$  ions. The ferric diphosphato aluminate is a proven compound. If in such a compound the phosphato groups are exchanged with  $\text{OH}^-$  ions in the presence of calcium one of the usual calcium phosphate compounds would be formed by the exchanged phosphorus. With iron present instead of calcium, as in an acid soil, an iron phosphate would be formed. If this hypothesis is valid, the increased amount of soluble phosphorus found at pH 7 would be due to the anion exchange between the  $\text{OH}^-$  and the phosphato group. Upon liberation from the complex the phosphoric acid would form one of the calcium phosphates.

Figure 3      Werner complex showing a theoretical calcium, iron or sodium clay and ferric diphosphato aluminate.



## SUMMARY

Fifty-eight soils of the Gloucester, Merrimac, Carver, Agawam, and Hadley soil series, varying in texture from coarse sandy loams to very fine sandy and silt loams, were taken from uncultivated and, so far as known, from unfertilized soils in various towns of the state.

The pH values were determined by the quinhydrone method. The lime requirement was determined by addition of small amounts of calcium hydroxide in water solution shaking between additions until pH equilibriums were attained.

Based on values calculated from the lime requirement, additions of calcium hydroxide were made to each soil so that the pH values were approximately 6.0, 6.5, and 7. After drying at 65° C., the solubility of the soil phosphorus at each pH value was determined by the Truog method.

In the range beginning at the natural soil pH value and up to pH 6.0, there was no increase or a slight decrease in the solubility of phosphorus. At pH 6.5 there was no increase in the phosphorus soluble in some soils. Other soils showed increases in the amount soluble. In those soils which showed no increase in the solubility of their phosphorus at pH 6.5 there was no increase at pH 7, while those soils which showed an increase in the solubility of their phosphorus at



pH 6.5 there was a marked increase at pH 7.

Those soils which showed increases in phosphorus solubility at pH 7 were the more finely textured soils, while those which failed to show such an increase were of coarser texture.

The percentages of clay were determined, and it was found that in those soils which showed no relationship between texture and phosphorus solubility ratio, there was a relationship between clay content and increase on phosphorus solubility.

It is suggested that soils high in clay show relatively large ratios, produced by division of the phosphorus soluble at pH 7 by that soluble at the natural acid pH value; that as the percentage of clay decreases this ratio decreases; and that in those soils which are very low in clay content there is a decrease in solubility of phosphorus at pH 7. Stated in another form, it would seem that soils which contain medium to large amounts of clay show an increase in soluble phosphorus when their pH is raised to 7 by the addition of calcium hydroxide.

Table 1    Origin of soils used.
----------------------------------

Gloucester Series

85-86	Sandwich
144-145	Leverett Village
175-176	West Andover
179-180	Hanover
193-194	Sharon
195-196	Walpole
197-198	Sharon
199-200	Sharon
201-202	Sharon
215-216	Shutesbury

Merrimac Series

53-54	Williamsburg
75-76	Hyannis
79-80	Eastham
111-112	Agawam
126-127	Agawam
134-135	Amherst
142-143	Leverett
165-166	Salisbury
171-172	Newburyport
177-178	Lynnfield
203-204	Sharon
205-206	Sharon

Carver Series

189-190	East Bridgewater
191-192	Whitman

Hadley Series

43-44	Southampton
221-222	Hadley Center

Agawam Series

101-102	North Amherst
128-129	Westfield

Table 3      Lime requirements      Gloucester series

Soil	Texture	pH	CaO ppm	CaO 7-pH
85T	fine sandy loam	4.40	2392	915
86S	sandy loam	4.80	1740	791
144T	" "	4.60	2978	1241
145S	" "	5.15	1283	693
175T	very fine sandy loam	4.70	2932	1275
176S	coarse sandy loam	5.10	2656	1398
179T	sandy loam	5.10	3390	1784
180S	" "	5.65	1832	1353
193T	fine sandy loam	4.35	3766	1421
194S	very fine sandy loam	4.75	1283	570
195T	fine sandy loam	4.95	3390	1653
196S	" " "	5.45	1466	946
197T	sandy loam	4.70	3848	1673
198S	fine sandy loam	5.00	2290	1145
199T	very fine sandy loam	4.40	4398	1691
200S	" " " "	5.30	1649	970
201T	" " " "	4.35	4764	1798
202S	" " " "	4.40	2015	775
215T	silty sand	4.85	4580	2130
216S	fine sandy loam	5.05	2290	1174
223T	" " "	4.25	4051	1466
224S	" " "	4.50	2575	1030

Samples T are top soils.      Samples S are sub-soils.



Table 4      Lime requirements      Merrimac series

Soil	Texture	pH	CaO ppm	CaO 7-pH
53T	sandy loam	5.35	2290	1388
54S	coarse sandy loam	5.35	458	278
75S	loamy sand	5.30	916	538
76S	" "	5.70	550	423
79T	" "	5.40	916	573
80S	sandy loam	5.35	320	194
111T	loamy sand	5.25	934	534
112S	" "	5.40	458	286
126T	very fine sandy loam	5.00	1044	522
127S	" " " "	5.30	495	291
134T	" " " "	5.20	1374	763
135S	sandy loam	5.65	916	678
142T	" "	6.10	916	1018
143S	" "	6.65	458	1308
165T	loamy sand	5.15	916	495
166S	" "	5.30	458	269
171T	sandy loam	5.05	2345	1203
172S	" "	4.75	1558	693
177T	" "	5.60	1374	982
178S	" "	6.00	916	916
203T	very fine sandy loam	4.95	916	447
204S	" " " "	5.70	687	528
205T	" " " "	4.80	1145	520
206S	fine sandy loam	5.30	687	404

**Table 5      Line requirements**

**Agawan, Carver,  
& Hadley series**

Sample	Texture	pH	CaO	CaO 7-pH
<u>Agawan series</u>				
101	sandy loam	4.55	3480	1416
102	coarse sandy loam	5.45	641	285
128	very fine sandy loam	5.30	2198	1293
129	fine sandy loam	5.45	458	295
<u>Carver series</u>				
189	sandy loam	4.30	3234	1198
190	" "	4.70	981	426
191	fine sandy loam	4.45	3836	1504
192	" " "	4.55	1078	440
<u>Hadley series</u>				
43	silt loam	4.75	2940	1306
44	" "	5.35	1960	1188
221	very fine sandy loam	5.55	1960	1352
222	" " " "	5.15	1960	1060

Table 6

Phosphorus solubility at various pH values.

45

Gloucester series

Soil	pH	P	pH	P	pH	P	pH	P	pH	P	pH	P
85	4.40	40	6.00	38	6.55	45	7.05	53	7.50	65	8.00	113
86	4.80	52	6.15	49	6.75	60	7.00	63	7.70	81		
144	4.60	58	5.95	56	6.60	58	7.00	60	7.60	65		
145	5.15	58					7.05	72	7.50	73		
175	4.70	36	6.15	33	6.60	39	7.00	60	7.50	69		
176	5.10	40	6.00	32	6.50	36	7.00	37	7.50	40		
179	5.10	96	5.95	90	6.70	100	7.00	114	7.55	114		
180	5.65	64			6.50	64	7.00	70	7.50	75		
193	4.35	48	6.10	46	6.45	48	7.00	72	7.55	76		
194	4.75	48	5.85	45	6.70	70	7.00	119	7.45	163		
195	4.95	44	6.20	40	6.55	48	7.00	58	7.50	64		
196	5.45	45			6.50	60	7.15	68	7.75	87		
197	4.70	91	5.70	87	6.70	99	7.00	128	8.20	135		
198	5.00	85	6.10	80	6.50	101	7.00	134	7.50	138		
199	4.40	74	6.00	75	6.60	78	7.00	143	7.60	145		
200	5.30	52			6.50	52	7.15	130	7.50	135		
201	4.35	43	6.00	40	6.50	40	7.15	68	8.00	72		
202	4.40	76	6.15	80	6.60	80	7.00	136	8.20	140		
215	4.85	49	6.05	49	6.50	50	7.00	58	7.50	60		
216	5.05	49	6.00	52	6.65	55	7.00	62	8.00	70		
223	4.25	48	6.20	48	6.80	70	7.00	70	8.00	76		
224	4.50	48	6.00	50	6.55	54	7.00	70	7.50	70		

P is phosphorus per 2,000,000 pounds of soil.

In each pair of soils the first is the top and the second the sub-soil.



Table 7

Phosphorus solubility at various pH values.

Merrimac series

Soil	pH	P	pH	P	pH	P	pH	P	pH	P
53	5.35	97	6.15	96	6.65	99	7.15	99	7.50	98
54	5.35	43	6.05	43	6.50	43	7.30	44		
75	5.30	49	6.25	48	6.55	49	7.00	65		
76	5.70	40	6.30	38	6.60	42	7.20	44		
79	5.40	55	6.05	53	6.50	58	7.15	72	8.30	85
80	5.35	39	6.00	37	6.50	40	7.00	40		
111	5.25	68	6.20	60	6.55	55	7.00	48	7.50	50
112	5.40	50					7.15	36		
126	5.00	49	6.00	46	6.55	63	7.00	116	7.50	120
127	5.30	52			6.50	71	7.15	142		
134	5.20	36					7.00	152		
135	5.65	74	6.30	65	6.50	75	7.00	80	8.20	80
142	6.10	74			6.60	72	7.00	70		
143	6.65	52					7.00	49		
165	5.15	56	6.10	49	6.50	50	7.00	46		
166	5.30	50	6.15	48	6.60	48	7.00	48		
171	5.05	42	6.05	40	6.50	42	7.00	45		
172	4.75	42	6.00	40	6.50	44	7.00	42		
177	5.60	76	6.05	70	6.55	80	7.00	88	7.50	92
178	6.00	58	6.00	58	6.50	64	7.00	69	8.00	79
203	4.95	125	5.95	120	6.65	144	7.05	193	8.00	188
204	5.70	71	6.15	68	6.45	69	7.00	142	7.50	142
205	4.80	35	6.20	34	6.55	71	7.05	112	7.80	116
206	5.30	78	6.00	70	6.60	80	7.15	82	8.05	84

P is phosphorus expressed in pounds per 2,000,000 of soil.

In each pair of soils the first is the top and the second the sub-soil.

Table 8      Phosphorus solubility at various pH values.

Soil	pH	P	pH	P	pH	P	pH	P
<u>Agawan series</u>								
101	4.55	56	6.00	58	6.50	54	7.15	56
102	5.45	64	6.10	56	6.45	58	7.00	56
128	5.30	72	6.05	70	6.60	88	7.20	116
129	5.45	80	6.25	84	6.55	90	7.05	110
<u>Carver series</u>								
189	4.30	44	5.95	42			7.05	44
190	4.70	36			6.65	34	7.25	36
191	4.45	44	6.15	48	6.50	44	7.05	52
192	4.55	40	6.00	40	6.60	40	7.15	52
<u>Hadley series</u>								
43	4.75	81	5.85	80	6.50	84	7.00	141
44	5.35	129	6.05	136	6.55		7.00	190
221	5.55	140			6.45	146	7.05	202
222	5.15	88	6.10	86	6.55	102	7.00	135

All results in tables 6, 7, and 8 at the natural pH and at pH 7 are averages. The results at other pH values are single determinations.

Table 10

Gloucester series arranged in  
order of buffer capacity ( $\frac{\text{CaO}}{7-\text{pH}}$ )

<u>Gloucester series</u>	
Soil	$\frac{\text{CaO}}{7-\text{pH}}$
215	2130
201	1798
179	1784
199	1691
197	1673
195	1653
223	1466
193	1421
176	1398
180	1353
175	1275
144	1241
216	1174
198	1145
224	1030
200	970
196	946
85	915
86	791
202	775
145	693
194	570



Table 11

Merrimac series arranged in  
order of buffer capacity ( $\frac{\text{CaO}}{7-\text{pH}}$ )

<u>Merrimac series</u>	
Soil	$\frac{\text{CaO}}{7-\text{pH}}$
53	1388
143	1308
171	1203
142	1018
177	952
178	916
134	763
172	693
135	678
79	573
75	538
111	534
204	528
126	522
205	520
165	495
203	447
76	423
206	404
127	291
112	286
54	278
166	269
80	194

Table 12

Gloucester series arranged in order of ratio of phosphorus soluble at natural pH to that soluble at pH 7, and per cent clay.

Soil	Texture	P	P @ pH7	Ratio	% Clay
194	very fine sandy loam	48	119	1 : 2.49	10
200	" " " "	52	130	1 : 2.50	10
199T	" " " "	74	143	1 : 1.93	8
202	" " " "	76	136	1 : 1.79	8
175T	" " " "	36	60	1 : 1.66	7
201T	" " " "	43	68	1 : 1.58	7
198	fine sandy loam	85	134	1 : 1.58	7
196	" " "	45	68	1 : 1.51	6
193T	" " "	48	72	1 : 1.50	7
224	" " "	48	70	1 : 1.46	6
223T	" " "	48	70	1 : 1.46	6
197T	sandy loam	91	128	1 : 1.41	6
195T	fine sandy loam	44	58	1 : 1.32	6
85T	" " "	40	53	1 : 1.32	5
216	" " "	49	62	1 : 1.26	5
145	" " "	58	72	1 : 1.24	5
86T	sandy loam	52	63	1 : 1.21	5
179T	" "	96	114	1 : 1.19	6
180	" "	64	70	1 : 1.19	5
215T	silty sand	49	58	1 : 1.18	1
144T	sandy loam	56	60	1 : 1.07	2
176	coarse sandy loam	40	37	1 : 0.93	1

Samples marked T are top soils.

Column marked P is phosphorus soluble at the natural pH.

Column marked P 7 is phosphorus soluble at pH 7.

Results are in pounds per 2,000,000 pounds of soil.

Table 13

Merrimac series arranged in order of ratio of phosphorus soluble at natural pH to that soluble at pH 7, and per cent clay.

Soil	Texture	P	P @ pH7	Ratio	% Clay
126T	very fine sandy loam	49	116	1 : 2.37	8
127	" " " "	52	122	1 : 2.35	9
134T	" " " "	72	152	1 : 2.11	9
204	" " " "	71	142	1 : 2.00	9
205	" " " "	70	112	1 : 1.60	7
203T	" " " "	125	193	1 : 1.54	7
75T	loamy sand	49	65	1 : 1.33	6
79T	" "	55	72	1 : 1.31	6
178	sandy loam	58	69	1 : 1.19	7
80	" "	39	46	1 : 1.18	6
177T	" "	76	88	1 : 1.16	5
135	" "	74	80	1 : 1.14	4
206	fine sandy loam	78	82	1 : 1.05	2
171T	sandy loam	42	44	1 : 1.05	1
53T	" "	97	99	1 : 1.02	2
54	coarse sandy loam	43	44	1 : 1.02	1
172	sandy loam	42	42	1 : 1.00	2
76	loamy sand	44	44	1 : 1.00	1
166	" "	50	48	1 : 0.96	1
142T	sandy loam*	74	70	1 : 0.95	6
143	" "	52	49	1 : 0.94	1
165T	loamy sand	56	46	1 : 0.82	1
112	" "	50	36	1 : 0.72	2
111T	" "	68	48	1 : 0.71	1

\* organic matter 9.50%.



Table 14

Agawan, Carver, and Hadley series  
arranged in order of ratio of phos-  
phorus soluble at natural pH to that  
soluble at pH 7, and per cent clay.

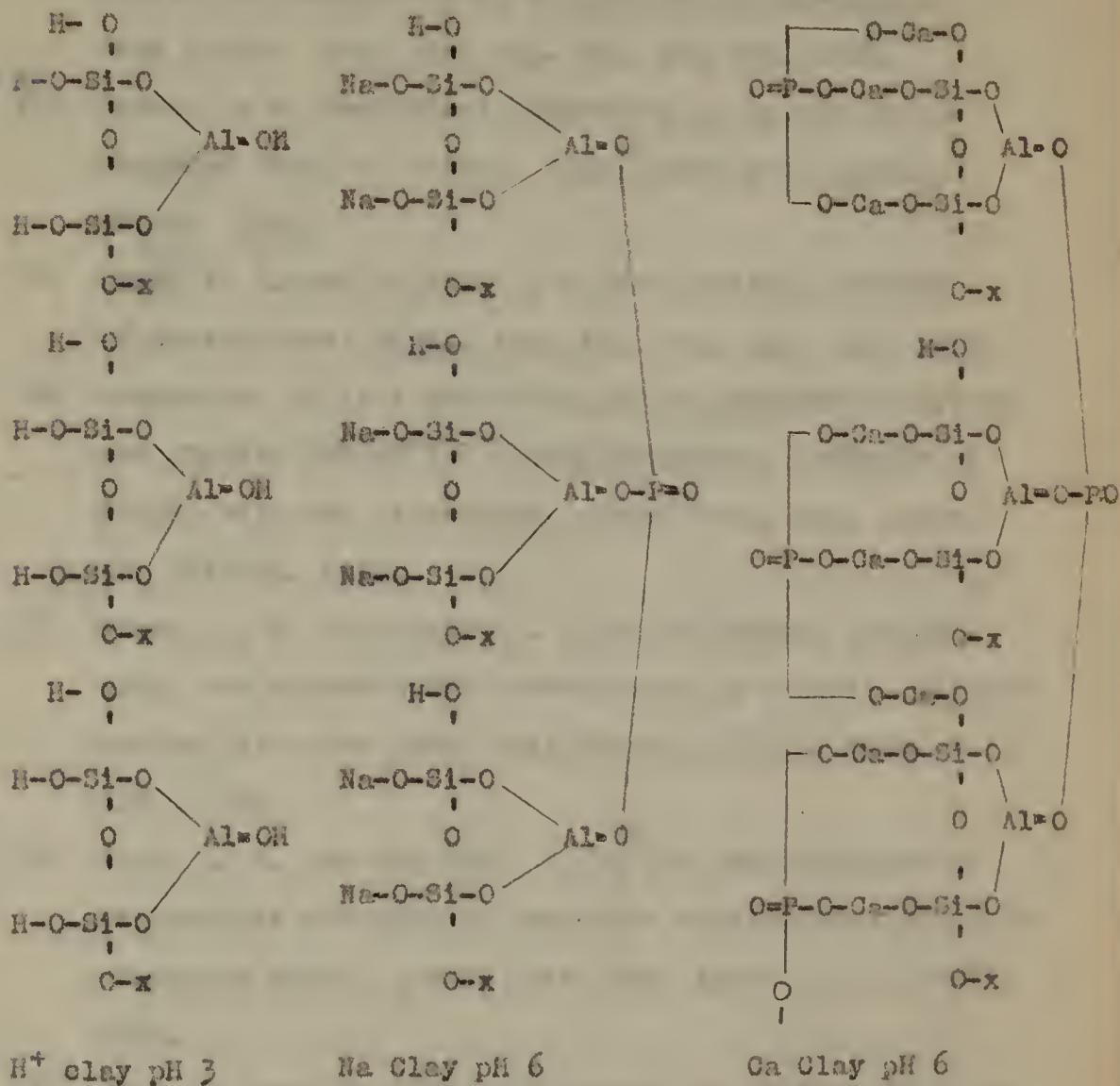
Soil	Texture	P	P @ pH7	Ratio	% Clay
<u>Agawan series</u>					
125T	very fine sandy loam	72	116	1 : 1.61	6
129	" " " "	80	110	1 : 1.27	6
101T	sandy loam	56	56	1 : 1.00	2
102	coarse sandy loam	64	56	1 : 0.87	2
<u>Carver series</u>					
192	fine sandy loam	40	52	1 : 1.30	6
191T	" " "	44	52	1 : 1.18	6
189T	sandy loam	44	44	1 : 1.00	4
190	" "	36	36	1 : 1.00	4
<u>Hadley series</u>					
43T	silt loam	81	141	1 : 1.74	8
44	" "	129	190	1 : 1.47	8
222	very fine sandy loam	88	135	1 : 1.13	7
221T	" " " "	140	202	1 : 1.44	7

Table 15

An arrangement of soils tested grouping them in their texture orders and giving comparative ratios of phosphorus soluble at the natural pH to that at pH8.

Textures	Gloucester	Merrimac	Carver	Agawam	Hadley
	<u>RATIOS OF P TO P at pH7</u>				
Very fine sandy loams	from 1:2.49 to 1:1.58	1:2.37 1:1.54		1:1.61	1:1.74 1:1.44
Fine sandy loams	from 1:1.51 to 1:1.21	1:1.33 1:1.19	1:1.30 1:1.18		
Sandy loams	from 1:1.19 to 1:1.07	1:1.08 1:1.04	1:1.00 1:1.00	1:1.00 1:1.00	
Coarse sandy loams	from 1:0.93 to	1:1.02 1:0.71			

Figure 1 Hypothetical combination of acid clay sodium clay and phosphate clay according to Scarseth.





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## VIII. ACKNOWLEDGMENT

The writer wishes to express his appreciation to the members of the committee under whose direction this paper was prepared, and to the members of the Agronomy and Chemistry Departments for their interest and timely advice.



