

EFFECT OF BASE SATURATION, pH AND EXCHANGE CAPACITY,
ON THE RELEASE OF PHOSPHORUS FROM
ACID SOILS CONTAINING ROCK PHOSPHATE

By

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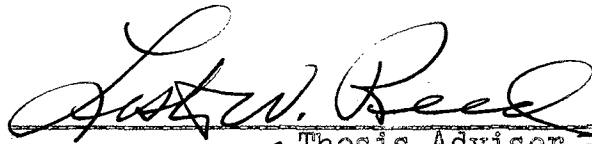
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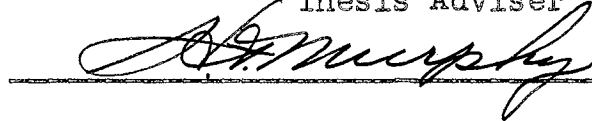
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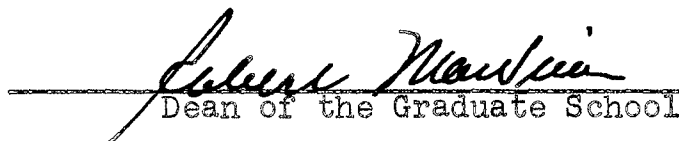
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452837

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INTRODUCTION

The use of fertilizer materials seems to be as old as cultivation of the soil. The manure pit occupies a prominent place in the courtyard of the farm homes in Europe, the "honey" bucket plays an important role in maintaining the soil fertility in many countries of the world, and manure obtained from cattle-feeding operations is considered to be profit on many farms in this country. Convenience, availability and cost have often been the factors determining the use of a fertilizer material. However, many fertilizer materials give good results on one soil under one set of conditions and different results on another soil. The soil itself is complex and its properties vary depending on the factors operating during its development.

Many phosphate-containing materials are used as fertilizer although all the factors in the soil which cause the release or fixation of the phosphorus from these materials is not well known. Rock phosphate has been used extensively in certain places but does not give equal response for all crops on all soils. In a recent textbook by Millar et al. (18)¹ the only suggestion for the use of rock phosphate is that it be finely ground and thoroughly mixed with the soil in the presence of decaying organic matter. There are several references (8, 16, 17) in the literature indicating that plants have made better growth from rock phosphate

¹ Figures in parentheses refer to Literature Cited.

when the soils were slightly to moderately acid, either naturally or through additions of acid clays or organic material.

This study was undertaken to determine if other factors might also be responsible for the release of phosphorus from rock phosphate. The cation exchange capacity and percent base saturation seem to be responsible for many of the chemical properties of the soil, and the objective of this study was to determine the effect of these factors on the release of phosphorus from rock phosphate.

LITERATURE REVIEW

Soils of the same reaction may vary considerably in their percent base saturation according to Pierre and Scarseth (20). They found that the highly weathered soils from the Piedmont Plateau and Coastal Plains had a lower degree of saturation at given pH values than less weathered soils. No relation was found between the organic matter content of soils or the nature of the bases present in the exchange complex and the percent base saturation of these soils at like pH values. The total exchange capacity of the colloids extracted from these soils showed a general, although imperfect, correlation with the percent base saturation values of the soils at like pH values. In general, the highly weathered soils were not as highly buffered as the less weathered soils.

Benne et al. (2) reported results of his own and previous workers. He stated that calcium ions did not precipitate phosphorus from solution, even in the presence of a high concentration of calcium ions, if the pH of the solution remained sufficiently low. Appreciable precipitation did not begin until the pH approached 5.5 and maximum precipitation or minimum solubility did not occur until the pH approached 7.6. When the pH of the system was sufficiently low, essentially all of the added phosphorus remained in solution. As the pH rose, iron precipitated the phosphate ion at pH 2 to 3. Aluminum ions precipitated the phosphate ion at pH 3 to 4. At pH 5 the precipitating

effect of aluminum ions and iron ions was negligible and calcium ions did not exert their maximum precipitative effect; hence, a maximum solubility appeared in the solubility curve. As the pH was raised the curve descended again due to the influence of calcium ions. The soil exchange complex when saturated with calcium caused phosphorus to be precipitated like a slightly soluble calcium salt of a weak acid. The phosphorus solubility curve for the soil used was similar to that with calcium carbonate but probably because of adsorption was displaced with respect to it and calcium oxide caused complete precipitation of phosphorus at pH 7.46 and above. Calcium carbonate did not raise the pH above neutrality and did not cause complete precipitation of the phosphorus. When the pH was raised from 7.0 to 8.0 with sodium hydroxide complete precipitation of the phosphorus did not occur.

Birch (3) reported results from field experiments on soils of East Africa within the pH range 4.7 to 6.3. He believed that a considerable amount of the phosphate ion available to the plant was associated with exchangeable bases, mainly calcium. The presence of phosphate ions in the soil was a function of the degree of base saturation insofar as base saturation governed the equilibrium distribution of the native soil phosphorus between the available base-linked form and the less available colloid-sorbed form. With decreasing pH and base saturation increasing amounts of colloid-sorbed phosphate was formed at the expense of

the base-linked phosphate. The degree of base saturation was therefore directly related to phosphate availability and, consequently, inversely related to plant growth (phosphate response). In view of the significant regressions obtained and the association of the exchangeable bases with a specific form of available phosphorus (super phosphate), it was suggested that until methods were worked out for determining the amount of base-linked phosphorus, exchangeable base data may be used for assessing phosphorus availability and response in acid soils. This method was contrasted with the more conventional methods of determining acid-soluble and adsorbed phosphorus which were not always specific regarding the form of phosphorus extracted. The values are difficult to interpret since they may represent the sum of a number of forms of different availabilities.

Burd (6) considered some forms of calcium phosphate to be the primary source material for phosphorus in soil systems. He concluded that most of these phosphate complexes were of secondary origin and the ratio of calcium to phosphorus was variable at the time of formation. Whether primary or secondary in origin, the relatively insoluble phosphorus compounds were mineral aggregates rather than molecular species. Dissolution of the phosphate ion occurs at the surface of mineral aggregates and the rate of solution is largely determined by the extent of surface, unless the solvent is of such nature and intensity as to break down completely the structural units of the mineral in

question. Phosphate ions escaping from such minerals or resulting from oxidation of organic phosphorus can be absorbed by certain types of clay minerals (kaolinitic types or by hydrated oxides of iron or aluminum) under certain conditions. Sorbed phosphate ions are not readily released to soil solution or plant roots under normal conditions existing in the soil-plant or soil--soil-solution interphase. The classification of the phosphate ion carrier in soils into one or the other of these types is desirable and can be accomplished by studying the relation of dissolved phosphate ions to changes in pH in mixtures of soil with dilute acid, water and alkali. The extent to which the phosphate ion comes into solution when the concentration of calcium in the soil solution is lowered can be demonstrated by comparing the phosphorus concentration of successive increments of displaced solutions. The effect of hydrogen ions, released by plant action, upon the phosphate ion carrier in a soil cannot be measured in vitro because the acid acts upon other soil constituents which release calcium ions and depress phosphorus solubility. The same objection holds for use of any solvent applied to the entire soil at equilibrium, inasmuch as the effect of the solvent upon the phosphate ion carrier cannot be isolated from the secondary effects on the nonphosphate calcium compounds in the soil. If the time of contact between the soil and solvent is shortened to the least that is practical it can be demonstrated that more phosphorus is released from some soils, under these conditions, than is freed at equilibrium. When this is the case

at least some of the secondary reactions, inescapable at equilibrium, have been eliminated. These data may thus reflect more nearly what would happen in the soil-plant interphase where hydrogen ions could act directly on the phosphate ion carrier. A considerable group of soils, the phosphate requirement of which had been demonstrated in pot experiments with oat plants, was studied by making very dilute acid extracts. Little relation could be demonstrated between the fertilizer requirements of the oats and extractable phosphorus when more than minimal amounts of hydrogen ions were involved, but the water extracts showed a high degree of correlation. The results confirmed the earlier conclusion that the concentration of calcium ions in the soil solution was the dominant influence in determining phosphorus concentration in the liquid phase of the soil. When the soil solution was displaced from the same soils, the second increment of solution obtained never gave substantial increases in phosphorus concentration over the first increment in the phosphorus-deficient soils, whereas the adequate phosphorus soils always showed increases. Whether the concentration of calcium was diminished by using a wide ratio of water to soil in water extracts, or by displacing the soil water at saturation, the lowered calcium concentration tended to be reflected in higher phosphate concentrations. Data reported by Burd (6) indicated a fairly constant relation between the results obtained by either means correlated with plant growth. Burd's results probably mean that the acquisition of phosphate ion by a plant

from a soil, in which the phosphorus component is relatively insoluble, is largely determined by the extent to which the plant itself shifts the equilibrium between calcium ions and phosphate ions in the soil solution or in the plant-soil interphase. The influence of plant-induced shifts in the equilibrium would appear to be a minor factor in organic soils. First, organic soils contain relatively little inorganic phosphorus and second, the very high concentration of calcium and magnesium in the soil solution would preclude a solvent effect on the phosphate ion as a result of plant action.

Burd and Martin (7) expressed the opinion that the soil solution at moisture contents favorable to plant growth did not have a high solute concentration and was not saturated in the ordinary sense of the word except with reference to phosphate ion and possibly the silicate ion. The growth of plants materially reduces the concentration of the constituents other than phosphate ion in the soil solution which are removed by the plant in substantial quantities. Considerable time, usually a number of months, was necessary for the soil solution subjected to the growth of a crop to regain its approximate previous concentration. Burd and Martin also discussed the behavior of solutes in soil of different moisture contents. In one group the concentration of ions (calcium, nitrate and chlorides) in a given soil solution was inversely proportional to the moisture content of the soil. The concentration of phosphate ions in solutions displaced from a given soil at different

moisture contents were equal. Potassium concentration in soil solutions displaced from a soil at a low moisture level was higher than that displaced from the same soil at a higher moisture content but the results were not in proportion to moisture content.

Parker and Tidmore (19) considered Burd's (6) observation that successive displacement of the soil solution extract removed salts and increased the solubility of the phosphorus. They believed that this explained the difference in the phosphate ion concentration in the soil solution and soil extracts. To obtain a higher concentration of phosphorus in the extract than in the soil solution the presence in the soil of a considerable amount of readily soluble phosphate ion was essential. When the readily soluble phosphate was not present the phosphate ion content of the extract would generally be lower than that of the soil solution. Parker and Tidmore concluded that at least two factors determined the phosphorus concentration of the soil solution or extract: (1). amount and nature of the phosphate compounds in the soil (precipitated calcium phosphate is more soluble than iron and aluminum phosphates), (2). amount and composition of salts in the soil solution or extract. A high concentration of calcium salts would depress the solubility of all forms of phosphorus in the soil, but the first factor is doubtless the more important of the two.

Teakle (24) found that the removal of calcium from the soil solution of a soil by means of ammonium oxalate caused a twenty to fiftyfold increase in phosphate ion concentration. This phosphate could be precipitated by the addition of calcium or iron to the soil and thereby reducing the phosphate ion concentration to the original figure. This action does not necessarily occur in soils containing phosphorus compounds of low solubility. It depends on the relation of the solubility products of calcium phosphate and calcium ions. Comparison of the solubility of various phosphates in pure solutions with the concentrations found in the soil solution suggests that the chemical properties of the compounds account for the behavior of soil phosphates. Adsorption of phosphate ion is unimportant, if it occurs at all in soils. Calcium is the most important base associated with the phosphate ion in the soil solution in neutral soils of the type studied. The main factors in depression of the solubility of calcium phosphate are calcium ions and calcium ions in the presence of hydroxyl ions. Hydroxyl ions alone probably cause the formation of a basic calcium phosphate with the liberation of some phosphate ions.

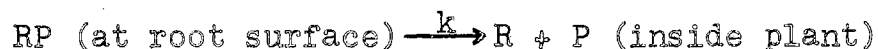
Joos and Black (17) equilibrated rock phosphate with bentonite at different pH values. After five months the bentonite phosphate mixture was mixed with sand and a test crop of Sudan grass was grown to determine phosphorus availability and release. They found availability of the phosphate rock was relatively high at pH 4.6 to 5.6 but was lower at pH 6.6.

Dean and Rubins (10) reported that the soil phosphate is composed of discrete particles and aggregates of variable composition. Some of these may have a relatively high phosphate solution potential whereas others may be insoluble. However, there was no reason to suppose that all parts of a root system do the same thing. They argued that the "phosphorus equilibrium potential" of the roots was higher than that of the clay, thus phosphorus would migrate from the clay to the root; however, if the potential of the clay was higher, the movement would be in the opposite direction. They studied the absorption of phosphorus by plants from a clay-water system and preliminary results with barley seedlings gave no evidence of a contact exchange or other contact effects between roots and clay particles which influenced the rate of absorption of phosphorus from clay-water systems.

Fried and Shapiro (12) studied the pattern of phosphorus release in soils of different phosphorus contents by three techniques: continuous soil leaching, successive hourly equilibration and intermittent leaching in the presence of growing plants. All three methods gave similar results. The pattern of phosphorus release for four low phosphorus-fixing soils could be predicted by assuming the phosphorus released was a desorption phenomenon as described by the Langmuir adsorption isotherm. The pattern of phosphorus release for the three high phosphorus-fixing soils could be predicted by assuming that in the presence of water a saturated solution

of a phosphorus compound was formed. The level of phosphorus in the initial water extract was not a good indication of plant-available phosphorus. Both the intensity of soil phosphorus release and the capacity of the soil to rapidly re-establish the equilibrium must be evaluated to adequately describe plant-available phosphorus in the soil.

Fried and Hagen (11) studied the rate of formation of soil solution phosphorus. Their measurements indicated that the renewal of phosphorus in the soil solution by dissolution of solid-phase phosphorus was rapid in comparison with the rate of phosphorus absorption by plants. The rate of absorption by plants, under otherwise equal conditions, thus appeared to be governed by the concentration of phosphorus in the solution in contact with the roots and not the rate of dissolution of solid-phase phosphorus. The limiting rate was associated with the plant, which according to Hagen and Hopkins is the turnover rate as represented by equation:



k = constant

P = phosphorus

R = regenerated carrier in the plant

The whole soil mass may not be effective in supplying phosphorus to the plant and the region in the immediate vicinity of the roots may be the only effective soil volume. This might be described as the effective soil volume. The rate of phosphorus movement in the soil should limit this volume. Fried and Hagen stated that the rate of phosphorus release

by the soil was at least 250 times as great as the rate of plant uptake. The effective soil volume would, therefore, be less than 0.4% of the total soil mass.

Salter and Barnes (21) studied the effect of liming on plant response to rock phosphate. In one of their experiments the efficiency of rock phosphate was 40 percent of super phosphate before liming. During the last six years of the experiment after the soil had been brought up to approximately pH 7.5 by repeated liming the rock phosphate showed an average efficiency (for corn, wheat and clover) of -1 percent. The efficiency ratings are the efficiencies per pound of phosphoric acid and not per pound of total fertilizer applied.

Cook (8) found that additions of hydrogen-saturated bentonite and organic and inorganic soil colloids greatly increased the availability of rock phosphate to crops like oats, millet and corn which otherwise do not feed well on it. Calcium-saturated bentonite did not increase rock phosphate availability. The hydrogen-saturated bentonite did not increase the availability of rock phosphate to buckwheat. The results of other experiments supported the contention that an increase in base saturation of soils lowers the immediate availability of rock phosphate to plants like corn and oats, but on the other hand tends to keep native soil phosphates and those added as soluble salts in the form of the more soluble calcium phosphates rather than the less available basic iron phosphate and other insoluble phosphates.

METHODS AND MATERIALS

This study was conducted to determine the effect of the percentage of base saturation of soil on the rate of release of phosphorus from rock phosphate applied to three Oklahoma soils.

The three surface soils studied were Norge, Bowie and Wilson. The Bowie and Wilson soils had been used in a previous study by Heilman (16). The Norge soil was obtained from an unfertilized area on the Agronomy Farm at Perkins, Oklahoma. Detailed descriptions of these soils are listed in the Appendix. The soils were dried and crushed with a roller to pass a 20-mesh sieve.

The soil characteristics for the three soils used in the experiment were determined by laboratory analysis and are shown in Table 1. The methods used follow:

Cation exchange capacity -- Cation exchange capacity was determined by displacing the cations with sodium from 1.0 N sodium acetate, Bower et al. (4).

Exchangeable cations -- Exchangeable cations were determined, using 1.0 N ammonium acetate to displace the cations (4). The amount of calcium, magnesium, potassium and sodium were determined with the Beckman Flame Spectro-

photometer with photomultiplier attachment.

- pH -- The pH was found by moistening the soils with distilled water to a thick paste, allowing 30 minutes for equilibrium and determining the pH with a Beckman Zero-matic pH meter.
- Organic matter -- Percent organic matter was obtained by oxidation with sodium dichromate in the presence of sulfuric acid, Walkley (25).
- Nitrogen -- Percent organic and ammonia nitrogen was determined by the method recommended by the Association of Official Agricultural Chemists (1) with the exception that selenium was added as a catalyst instead of copper or mercury, and sodium sulfate was added to the digestion flask to raise the boiling point, Harper (15).
- Phosphorus -- Total phosphorus was determined according to Shelton (22).
Available phosphorus was determined by two methods: 0.1 N acetic acid, suggested by Harper (14), but modified by using hydrochloric acid in place of sulfuric acid in the molybdate solution; 0.025 N hydrochloric acid plus 0.03 N ammonium fluoride, Bray (5).

Mechanical
analysis

-- The mechanical analysis for each of the soils was determined according to the method suggested by Day (9). "Calgon" plus sodium carbonate was used as the dispersing agent.

Portions of each of the three soils were acidified by placing the soil on a filter paper in a Buchner funnel and leaching with 0.01 N HCl (an amount equal to five times the exchange capacity of each soil). The excess salts were removed by leaching with distilled water until chloride free as indicated by the silver nitrate-nitric acid test.

Another portion of each of the soils was saturated with calcium. The soil was placed on a filter paper in a Buchner funnel and leached with 0.5 N calcium chloride (an amount equal to 200 times the cation exchange capacity). Excess salts were removed by washing with distilled water until chloride free.

Exchangeable cations were determined for each of the acidified and calcium-saturated soils (4). The percent base saturation was calculated for each of the untreated, acidified, and calcium-saturated soils.

Acidified Norge soil and untreated Norge soil were mixed together to prepare a 35% base saturation sample. The 55% and 75% base saturations were prepared by combining acidified and calcium-leached Norge soil. The 35% and

TABLE 1

SOIL CHARACTERISTICS AS DETERMINED BY LABORATORY ANALYSIS

Determination	Soils			
	(1)Norge	(2)Bowie	(3)Wilson	
Cation Exchange Capacity	*	8.69	2.39	13.57
Exchangeable Cations	*	4.84	1.78	9.24
Calcium	*	3.20	1.60	6.37
Magnesium	*	1.32	0.08	1.74
Potassium	*	0.28	0.08	0.13
Sodium	*	0.04	0.02	1.00
Percent Base Saturation		56.	74.	68.
pH		5.2	6.2	5.3
% Organic Matter		1.14	0.62	1.06
% Nitrogen		.0523	.0323	.0618
Total Phos #/Acre		194.	104.	164.
Available Phosphorus #/Acre	**	2.	11.	1.
" " "	***	2.	3.	2.
Mechanical Analysis	<u>Diameter in mm.</u>			
% Sand	.05 - Above	60.5	81.5	45.0
% Coarse Silt	.02 - .05	18.0	9.5	27.0
% Fine Silt	.005 - .02	9.0	6.7	12.5
% Coarse Clay	.002 - .005	1.5	1.5	1.5
% Fine Clay	Below - .002	11.0	0.8	14.0

* me. per 100 gm. soil

** 0.1 N Acetic Acid

*** 0.025 N HCl + 0.03 N NH₄F

55% base saturations for the Bowie and Wilson soils were prepared by mixing acidified and untreated samples of each soil. The 75% base saturation for the Bowie and Wilson soils was prepared from calcium-leached soil and untreated soil. The three soils, Norge, Bowie and Wilson are called soils 1, 2 and 3 respectively in the following discussion.

Rock phosphate equivalent to 1500 pounds per acre was mixed thoroughly with each of the soils, covered with water to a depth of about one-eighth inch, and equilibrated for three days with occasional stirring. The pH of the soils was determined four hours after the water was added and at the end of the three day period.¹ Following the equilibration period the water was allowed to evaporate from the soils at room temperature; the dried soils were crushed to pass a 20-mesh sieve and four 5-gram samples were weighed from each of the twelve soils.

A tablespoon of very fine sand, which had been leached with an equal volume of 50% hydrochloric acid and washed chloride free, was placed in the bottom of leaching tubes as described by Fried (11). The five-gram samples of the soil-rock phosphate mixture were thoroughly mixed with 20 grams of the fine sand and placed in the bottom of the leaching tubes and another tablespoon of fine sand was layered over the soil-sand mixture. In addition, two teaspoons of coarse sand (20 mesh) were layered over the fine sand. Distilled water was forced into the bottom of the leaching tubes with a funnel and rubber hose twelve hours

¹ See Table 2.

before the leaching process started (11). This procedure was found to aid materially in reducing the amount of suspended material which was leached out of the sample. The leaching tubes were then filled with distilled water to the level which would give the desired leaching rate. Constant-head water reservoirs were placed over the leaching tubes with discharge tubes at the desired level. In a few cases it was necessary to increase the head of a leaching tube by making an extension with a section of large glass tubing and a rubber stopper.

TABLE 2

FOUR-HOUR AND THREE-DAY EQUILIBRIUM pH OF EACH OF THE SOILS AT THE VARIOUS BASE SATURATIONS

Soil	% Base Saturation	4-hour equilibrium pH	3-day equilibrium pH
1	35	4.0	4.6
	55	4.5	5.2
	75	5.9	6.4
	56 *	4.9	5.4
2	35	4.3	5.1
	55	4.9	5.7
	75	5.2	6.0
	74 *	6.0	6.9
3	35	3.2	4.2
	55	4.1	5.1
	75	5.7	6.3
	68 *	5.3	6.0

* Normal

Twelve samples, that is, each of the three soils untreated, 35, 55, and 75% base-saturated, were analyzed at one time. They were leached with 100 ml. of distilled water

five times each day at half-hour intervals for six consecutive days. The first day the first and last samples were analyzed for phosphorus and the last five days all samples were analyzed. The results from the first day's run were not included in the statistical analysis.

All leachates were filtered through a Buchner funnel on a separatory funnel. A quantitative analysis grade of filter paper was used with sufficient Celite* to noticeably decrease the filtering rate of the samples.

After the leachates were filtered, a 25 ml. aliquot from each sample was analyzed for phosphorus. A Bausch and Lomb spectrophotometer with matched 1 by 6 inch sample tubes was used to read sample density at a wave length of 700 millimicrons with a type 1P⁴O photocell and red filter. A phosphorus curve was prepared by plotting machine readings against ppm of phosphorus. The standards used to develop the curve were prepared by dispensing known quantities of 5 ppm phosphorus, 0, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 3.....10 ml. from an accurate burette into 100 ml. volumetric flasks. Ammonium molybdate and stannous chloride were used to develop the color and distilled water was used to make up the volume. The color of the soil leachate samples and standards was read between 5 and 20 minutes after development.

The time of leaching of the samples remained fairly constant throughout the experiment. The range in time of

* Johns Manville Trademark (Infusorial Earth)

leaching was from $5\frac{1}{4}$ to 8 minutes for the first leach the first day to $6\frac{1}{2}$ to 10 minutes the fifth leach on the sixth day. Fried (11) indicated that time is a factor in the rate of removal of phosphorus from a soil by leaching but his observation was not verified in this experiment.

The calcium content of the leachates was determined several times during the experiment on the Beckman Flame Spectrophotometer with photomultiplier attachment and the results are listed in the Appendix.

The data, in ppm of phosphorus leached from the soil, were multiplied by a factor of 100, transformed to logs, punched on IBM cards and the AOV was calculated on a 650 IBM computer. Sums of squares were obtained for the main effects and interactions. The sums of squares containing replications, except the main effect, were used as the error term. The data are in logs of 100 times ppm phosphorus in the soil. The analysis of variance for the data from each of the three soils is found in the Appendix.

RESULTS AND DISCUSSION

This experiment was designed to determine the effect of percent base saturation on the release of phosphorus from rock phosphate applied to acid soils. Through the aid of statistics the release pattern of water-soluble phosphorus between successive days, consecutive daily leachings, and for different base saturations for each of the three soils was interpreted.

The F values for linearity of log days were found to be highly significant for all three soils. However, some significant curvature was found in soils 1 and 2. Figure 1 shows the effect of days on the release of phosphorus from the three soils. The Analysis of Variance tables in the Appendix show the F values.

Leachings were very highly significant in linearity, as shown in Figure 2. Some significant curvature in log consecutive daily leachings was found in soils 2 and 3 but none in soil 1. The effect of consecutive daily leachings on the release of phosphorus is shown in Figure 2. The non-linearity in the phosphorus release curve for soil 2 seems to be due to low exchange capacity. The water dissolved a relatively high amount of phosphorus the first leaching each day from soil 2 but the amount dissolved for the following leachings dropped considerably, as shown in Figure 3. The decrease in the rate of solution for the following consecutive daily leachings was then more gradual as it asymptotically approached the "minimum"

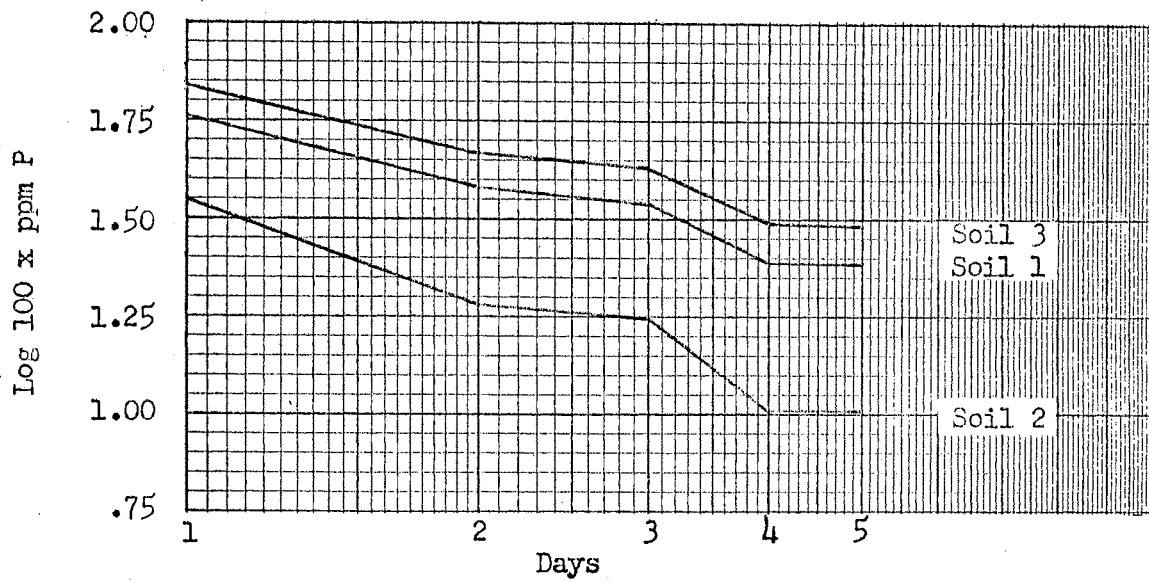


Figure 1. Effect of Days on Release of Phosphorus from the Three Soils.

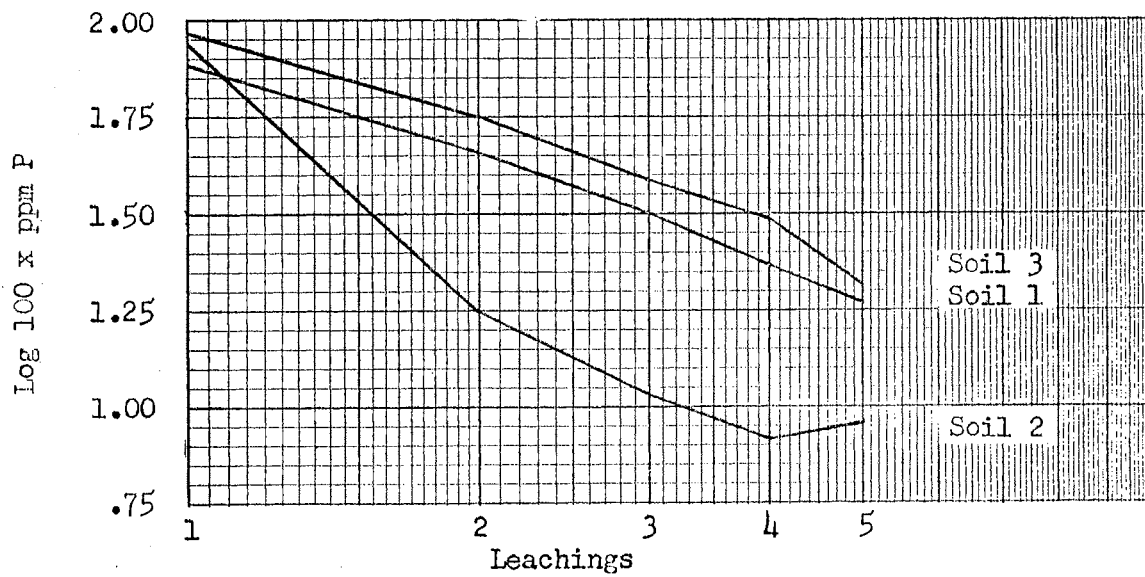


Figure 2. Effect of Consecutive Daily Leachings on Release of Phosphorus from the Three Soils.

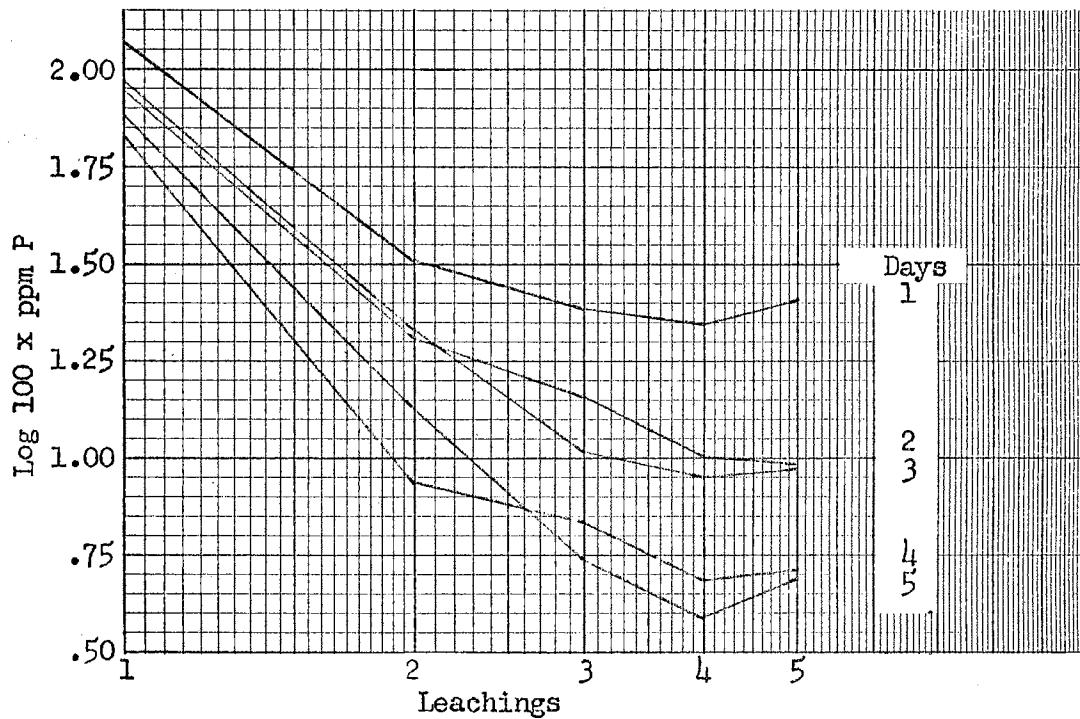


Figure 3. The Release of Phosphorus from Soil 2 by Days Plotted Against Consecutive Daily Leachings.

TABLE 3

THE EFFECT OF CONSECUTIVE DAILY LEACHINGS ON THE RELEASE OF PHOSPHORUS FROM SOIL 2 ON SUCCESSIVE DAYS.

Day	Mean phosphorus (Log 100 x ppm P) released from soil 2 by leaching				
	1	2	3	4	5
1	2.0752	1.5178	1.3845	1.3526	1.4164
2	1.9531	1.3129	1.1598	1.0068	0.9829
3	1.9702	1.3303	1.0248	0.9509	0.9730
4	1.8338	0.9379	0.8499	0.6811	0.7299
5	1.8833	1.1324	0.7424	0.5898	0.6893

solution rate. Theoretically there would always be some phosphorus released from infinite leachings and soil 2 rapidly approaches this limit. When consecutive daily leachings were plotted over log days for each of the 3 soils, the line of leach 1 was gradually downward for successive days, as shown in Figure 4. The drop was more pronounced for each successive leaching for soils 1 and 3. With soil 2 the greatest interval was between leach 1 and leach 2. The interval between consecutive leachings 2 and 3 was less and the last three leachings were almost together.

The effect of base saturation on the release of phosphorus is shown in Figure 5. This figure indicates the relationship between percent base saturation of the three soils with differing exchange capacities and the release of phosphorus from rock phosphate. Soil 3 with the highest exchange capacity released the greatest amount of phosphorus at the 35 and 55% base saturation. It released less than soil 2 or 1 when all were at the 75% saturation level. This seems to indicate that the soils with high exchange capacity and high percentage base saturation may release a greater amount of calcium ions into the soil solution which retards the release of phosphorus more than soils of a lower exchange capacity and a high percentage base saturation. The 35, 55, 75 and normal percent base saturations are designated as saturation 1, 2, 3 and 4, respectively, throughout the discussion.

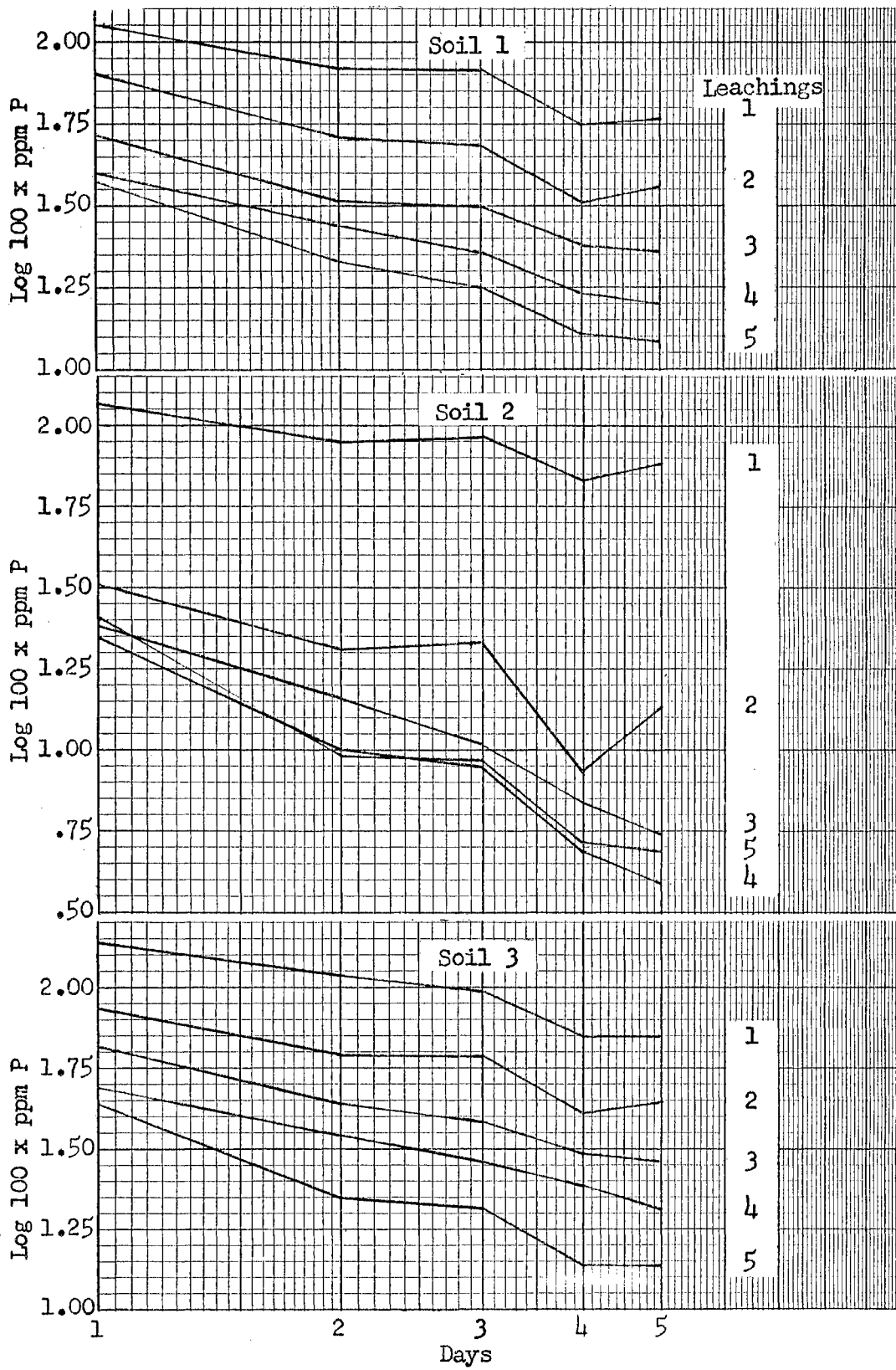


Figure 4. The Release of Phosphorus from the Three Soils by Consecutive Daily Leachings Plotted Against Days.

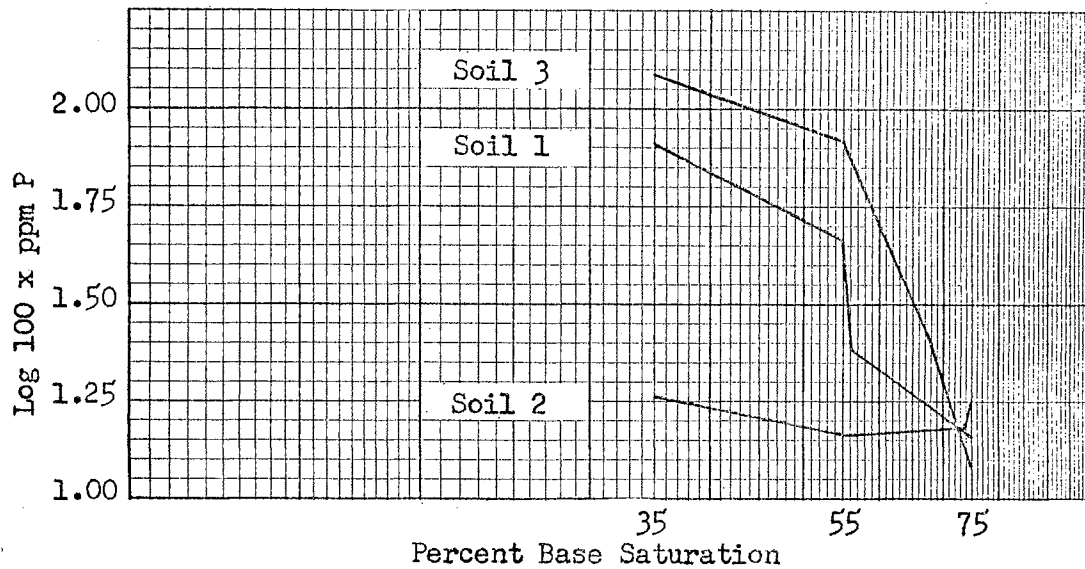


Figure 5. Effect of Percent Base Saturation on Release of Phosphorus from the Three Soils.

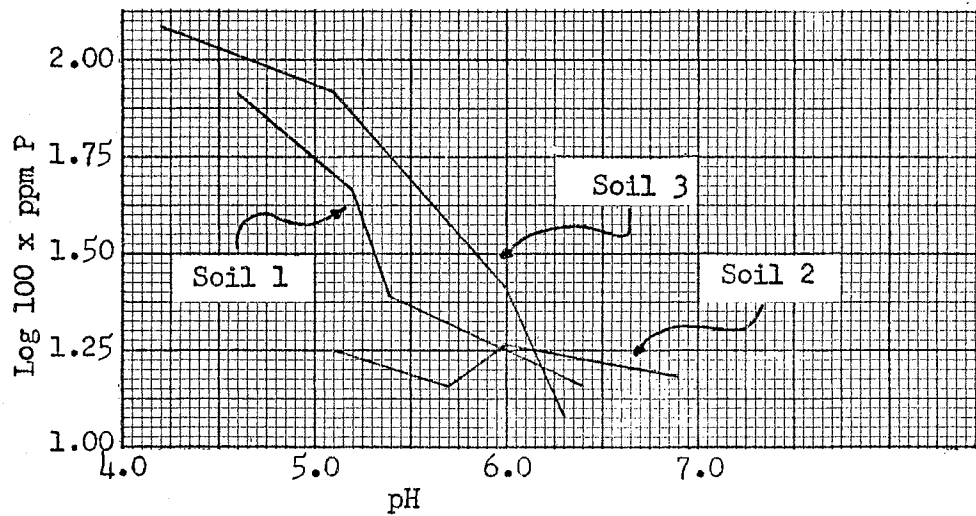


Figure 6. Effect of 3-day Equilibrium pH on the Release of Phosphorus from the Three Soils.

The pH of each of the soils at the various saturation levels was determined following a 3-day equilibrium period with the rock phosphate. These values were noticeably higher than those obtained about 4 hours following the addition of water to the rock phosphate and soil. The use of the 3-day equilibrium pH values in place of the base saturation percentages resulted in higher F values for linearity and lower curvature in the partition of the sums of squares for soils 1 and 3, and but little change in soil 2. This seems to indicate that the pH of these soils is a slightly better measure of the release of phosphorus than the percent base saturation. The relation of the 3-day equilibrium pH to the release of phosphorus from rock phosphate is shown in Figure 6.

It appears that the calcium ions from the rock phosphate replaced hydrogen ions on the clay during the period of equilibration, forming a phosphorus compound or compounds with a higher solubility than rock phosphate. This new phosphorus compound is partially removed by rapid, successive leachings, leaving the clay partially saturated with calcium. The partial saturation of the clay with calcium reduces the amount of available exchange sites, or hydrogen ions, in the clay and lowers the rate at which the phosphorus equilibrium compounds can be formed and the total amount that can be formed in a unit period of time. This renewal equilibrium occurs following each leaching but the intervals between passes and days were uniform and the full effect could not be observed in the experiment.

Two replications of the experiment were leached again after an interval of time following the sixth day of the experiment, six days for replication 2, and eleven days for replication 4. The ppm of phosphorus obtained from the two replications were averaged together for each of the six days in the experiment and the subsequent leaching. The difference between the six and eleven-day interval appeared to be comparable to the differences between the two replications. The 35% saturation for all three soils produced the highest amount of phosphorus in the leachates, approximately equal to the amount removed by the first leaching on the third day of the experiment, as shown in Table 4. The 55% saturation released slightly less phosphorus than obtained in the third day for soil 3, equal to day 1 for soil 1 and greater than any of the 5 days of the experiment or the preliminary day for soil 2. The 75% saturation and "normal" soils released more phosphorus than any of the first leachings of any of the days in the experiment.

These data indicate that the 3-day equilibrium period was not sufficiently long for the soluble phosphorus compounds to approach equilibrium. However, it does not seem to have altered the over-all results that would have been obtained had a longer initial equilibrium period been used.

Significant interactions were found between days and saturations for all three soils, as shown in the Analysis of Variance tables in the Appendix. They were due primarily to the erratic amounts of phosphorus released by the normal and

TABLE 4

EFFECT OF AN EQUILIBRATION PERIOD FOLLOWING SIX SUCCESSIVE DAYS OF LEACHING.

Soil	Percent Base Saturation	Mean phosphorus from two replication (Log 100 x ppm P) released from soils in Days						
		0	1	2	3	4	5	Later
1	35	2.832	2.611	2.426	2.346	2.196	2.100	2.338
	55	2.294	2.164	2.127	2.097	1.982	1.954	2.164
	75	1.079	1.176	1.380	1.447	1.301	1.431	1.806
	56	1.845	1.785	1.663	1.740	1.556	1.505	1.886
2	35	2.571	2.434	2.281	2.114	1.869	1.845	2.158
	55	1.973	2.025	1.939	1.968	1.881	1.839	2.107
	75	1.851	1.973	1.924	1.973	1.934	1.929	2.086
	74	1.732	1.653	1.602	1.892	1.851	1.851	2.137
3	35	3.316	2.899	2.673	2.549	2.365	2.152	2.494
	55	2.714	2.587	2.415	2.305	2.170	2.072	2.255
	75	1.301	0.845	1.079	1.322	1.431	1.342	1.415
	68	1.690	1.732	1.623	1.740	1.663	1.699	1.813

75% saturations of soils 1 and 3; however, the phosphorus released from soil 2 with its low exchange capacity was erratic for all saturations from day to day. Interactions between days and saturations are shown in Figures 7, 8 and 9. These figures (for each of the three soils) also indicate how each of the three normal soils compare with their respective synthesized soils. Saturation 4 for each soil follows the patterns set by the other saturations but the amount of phosphorus released was lower than would be expected from its base saturation. It is possible that the correlation might have been better if the soils had been allowed a longer period of time to come to equilibrium before the rock phosphate was added.

Significant interactions at the one percent level were found between leaches and saturations in soil 2. This seemed to be due to the low exchange capacity. The graph of these interactions is shown in Figure 10. Leach and saturation interaction for soil 1 was significant at the five percent level. This appeared to be displacement due to the 56 percent base saturation of the "normal" soil. It did not fit the pattern set by the formulated soils when plotted over saturations, as shown in Figure 11.

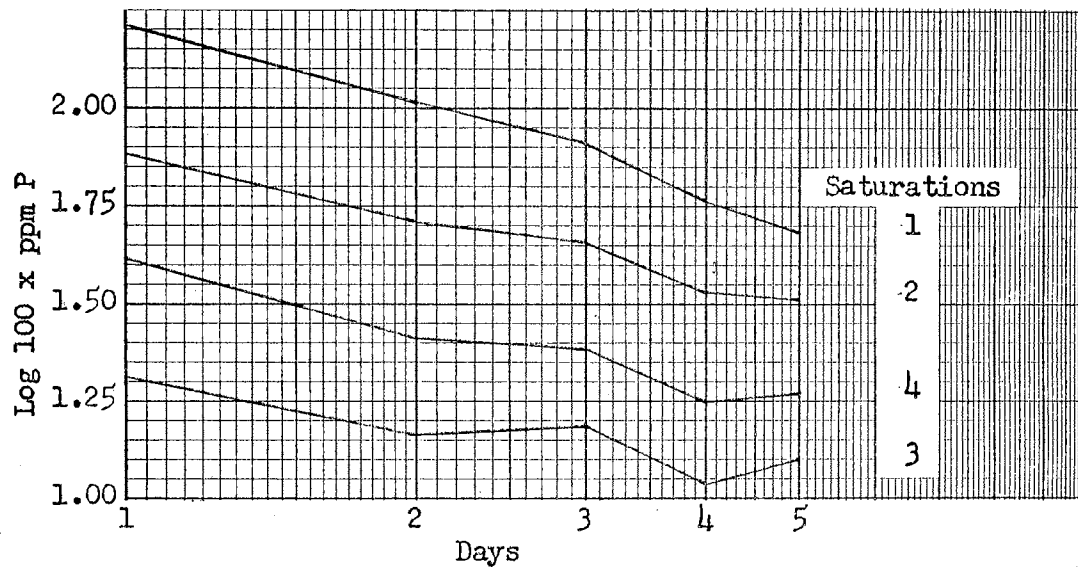


Figure 7. Release of Phosphorus from Soil 1 for Saturations Plotted Against Days.

TABLE 5

EFFECT OF SATURATIONS ON THE RELEASE OF PHOSPHORUS FROM SOIL 1 ON CONSECUTIVE DAYS.

Day	Mean phosphorus (Log 100 x ppm P) released from soil 1 by saturations:			
	1	2	3	4
1	2.2102	1.8856	1.3225	1.6204
2	2.0217	1.7150	1.1709	1.4279
3	1.9200	1.6612	1.1972	1.3984
4	1.7616	1.5336	1.0376	1.2549
5	1.6838	1.5150	1.1070	1.2730
% Base Saturation	35%	55%	75%	56%

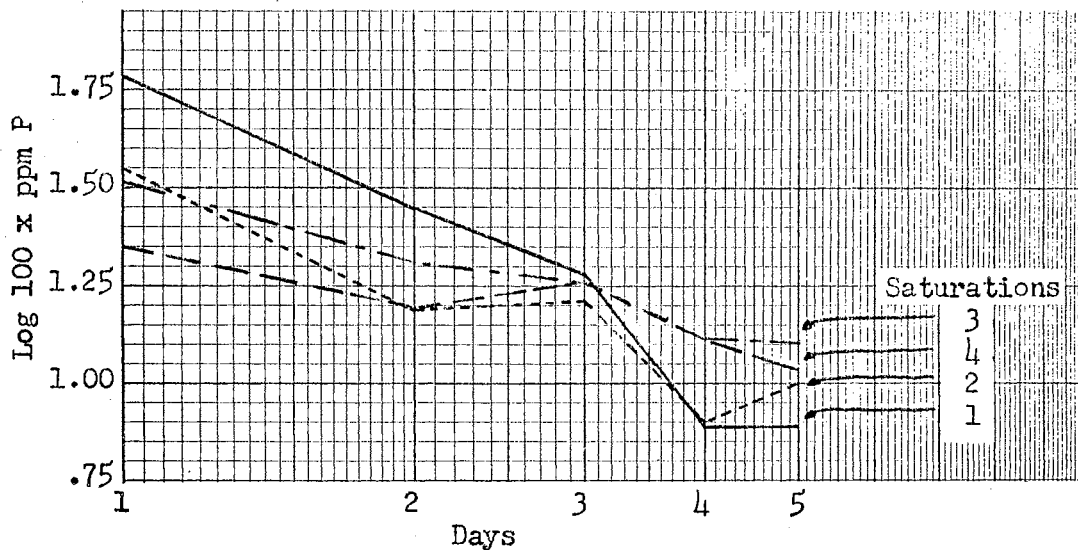


Figure 8. The Release of Phosphorus from Soil 2 for Percent Base Saturations Plotted Against Days.

TABLE 6

EFFECT OF BASE SATURATION ON THE RELEASE OF PHOSPHORUS FROM SOIL 2 ON CONSECUTIVE DAYS

Day	Mean phosphorus (Log 100 x ppm P) released from soil 2 by saturation			
	1	2	3	4
1	1.7778	1.5464	1.5218	1.3512
2	1.4502	1.1834	1.3072	1.1917
3	1.2799	1.2074	1.2569	1.2552
4	0.8840	0.9003	1.1218	1.1201
5	0.8892	1.0003	1.1085	1.0317
Base Saturation	35%	55%	75%	74%

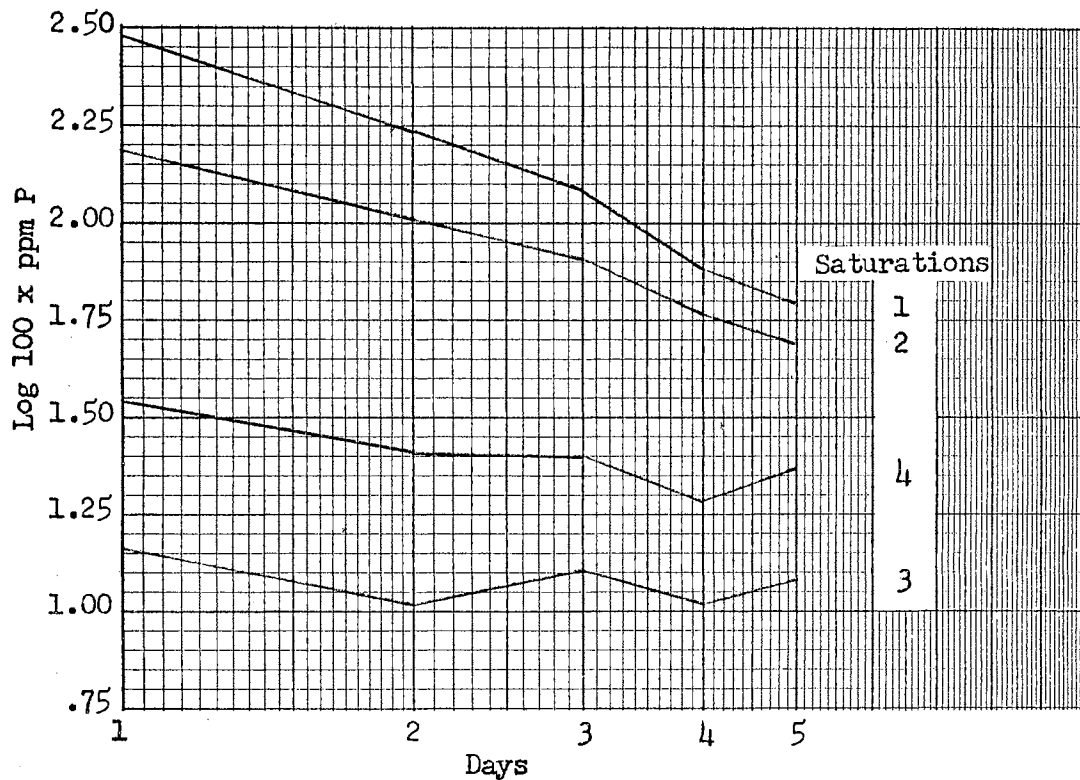


Figure 9. The Release of Phosphorus from Soil 3 for Percent Base Saturations Plotted Against Days.

TABLE 7

EFFECT OF BASE SATURATION ON THE RELEASE OF PHOSPHORUS FROM SOIL 3 ON CONSECUTIVE DAYS

Day	Mean phosphorus (Log 100 x ppm P) released from soil 3 by saturation			
	1	2	3	4
1	2.4812	2.1900	1.1568	1.5404
2	2.2407	2.0141	1.0212	1.4108
3	2.0859	1.9142	1.1144	1.4017
4	1.8780	1.7744	1.0188	1.2928
5	1.7899	1.6938	1.0851	1.3682
Base Saturation	35%	55%	75%	68%

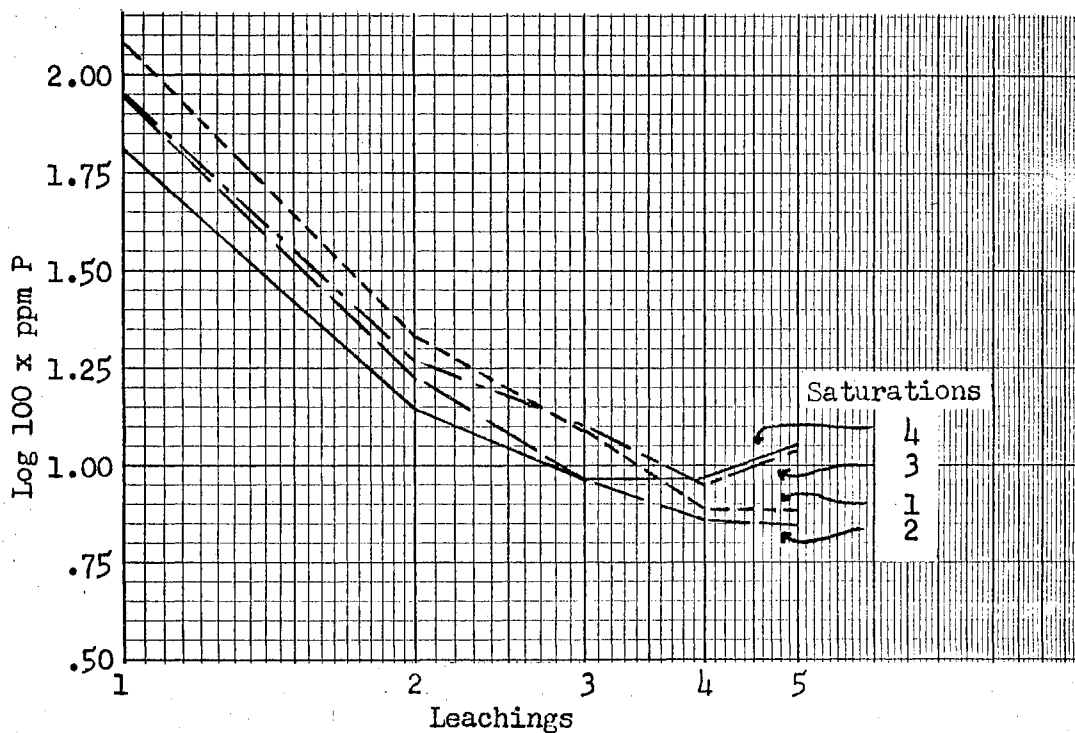


Figure 10. The Release of Phosphorus from Soil 2 for Percent Base Saturations Plotted Against Consecutive Daily Leachings.

TABLE 8

EFFECT OF BASE SATURATIONS ON THE RELEASE OF PHOSPHORUS FROM SOIL 2 BY CONSECUTIVE DAILY LEACHINGS.

Leaching	Mean phosphorus (Log 100 x ppm P) released from soil 2 by saturation			
	1	2	3	4
1	2.0778	1.9367	1.9452	1.8128
2	1.3343	1.2267	1.2785	1.1455
3	1.0929	0.9681	1.0984	0.9698
4	0.8879	0.8560	0.9538	0.9673
5	0.8881	0.8503	1.0404	1.0544
Base Saturation	35%	55%	75%	74%

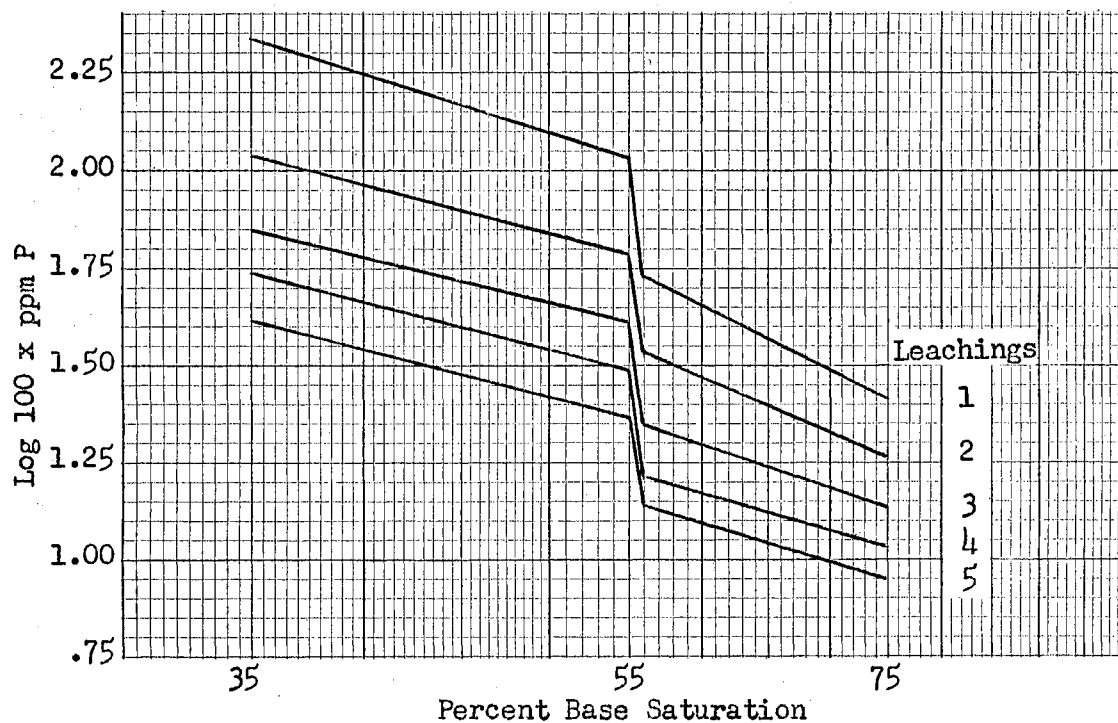


Figure 11. The Release of Phosphorus from Soil 1 for Successive Daily Leachings Plotted Against Percent Base Saturations.

TABLE 9

EFFECT OF BASE SATURATION ON THE RELEASE OF PHOSPHORUS FROM SOIL 1 BY SUCCESSIVE DAILY LEACHINGS.

Leaching	Mean phosphorus (Log 100 x ppm P) released from soil 1 by saturation			
	1	2	3	4
1	2.3374	2.0316	1.4239	1.7317
2	2.0441	1.7919	1.2786	1.5341
3	1.8576	1.6285	1.1454	1.3544
4	1.7416	1.4847	1.0339	1.2126
5	1.6166	1.3736	0.9533	1.1418
Base Saturation	35%	55%	75%	56%

The calcium content of the leachates of 0 day (not included in the statistical analysis) was determined on two of the replicates. Two of the leachates contained about 2.5 ppm calcium for the first leach of 0 day.¹ All other values were lower for both replications. The calcium content of the fifth leach was lower in most cases than the first leach. There appeared to be no correlation between the percent base saturation and the amount of calcium released. If there were a significant correlation between the calcium content of the soil solution and the base saturation, the large volume of leachates may have distorted these values.

The effect of exchange capacity on the release of phosphorus was further demonstrated by comparing it with leaches. In Figure 12 the means for leaches for each of the soils was plotted over the exchange capacity. This again demonstrates what soils tests sometimes show: two soils may seem to contain the same amount of phosphorus but one soil may release phosphorus at a much faster rate than another soil.

Exchange capacity and days are compared in Figure 13. These data indicate that over a period of time, the soils with a higher exchange capacity release more phosphorus from rock phosphate than soils of a lower exchange capacity.

Figure 14 is a graphic representation of the effect of base exchange capacity and pH on the release of phosphorus

¹ See Table 13

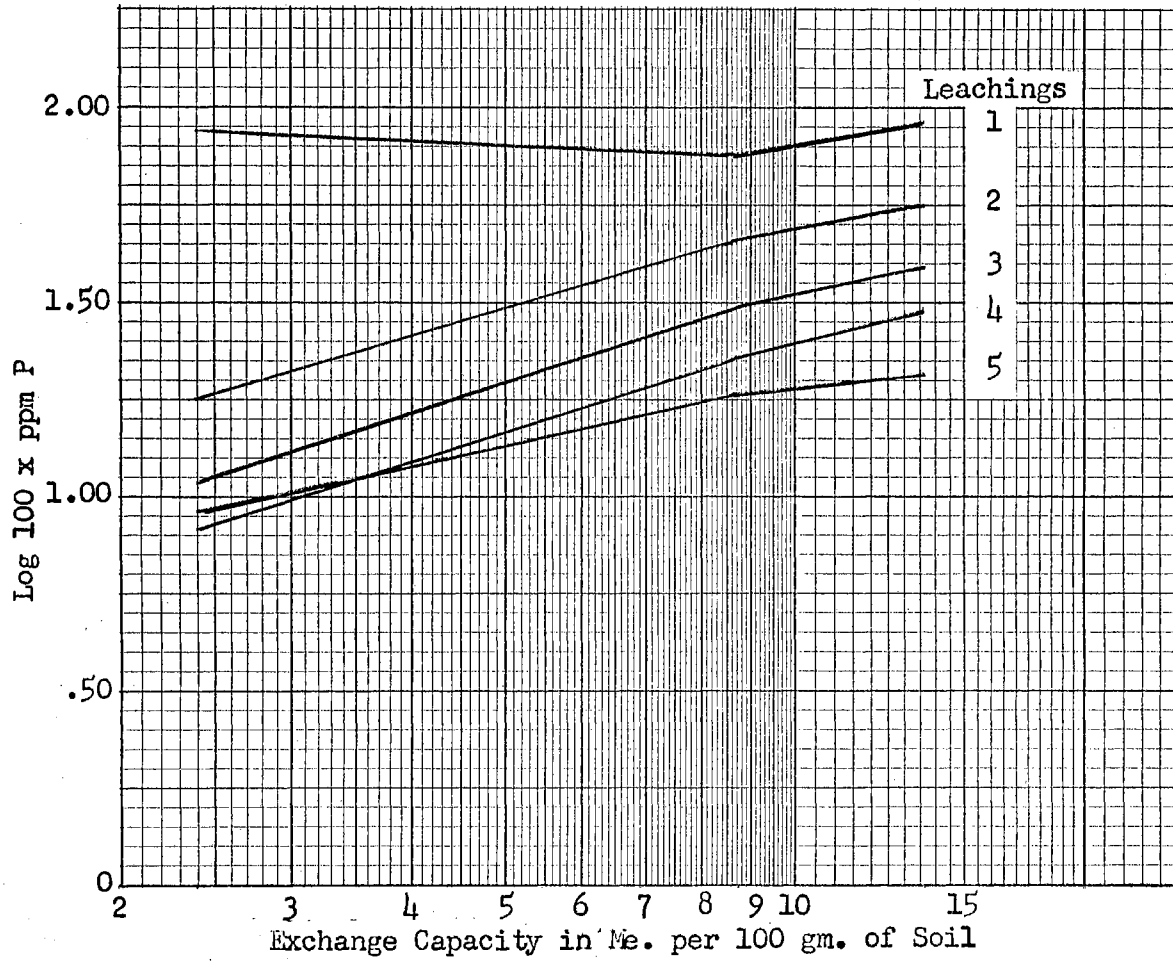


Figure 12. Phosphorus Released by Consecutive Daily Leachings of Each of the Soils Plotted Against the Exchange Capacity of Each of the Soils.

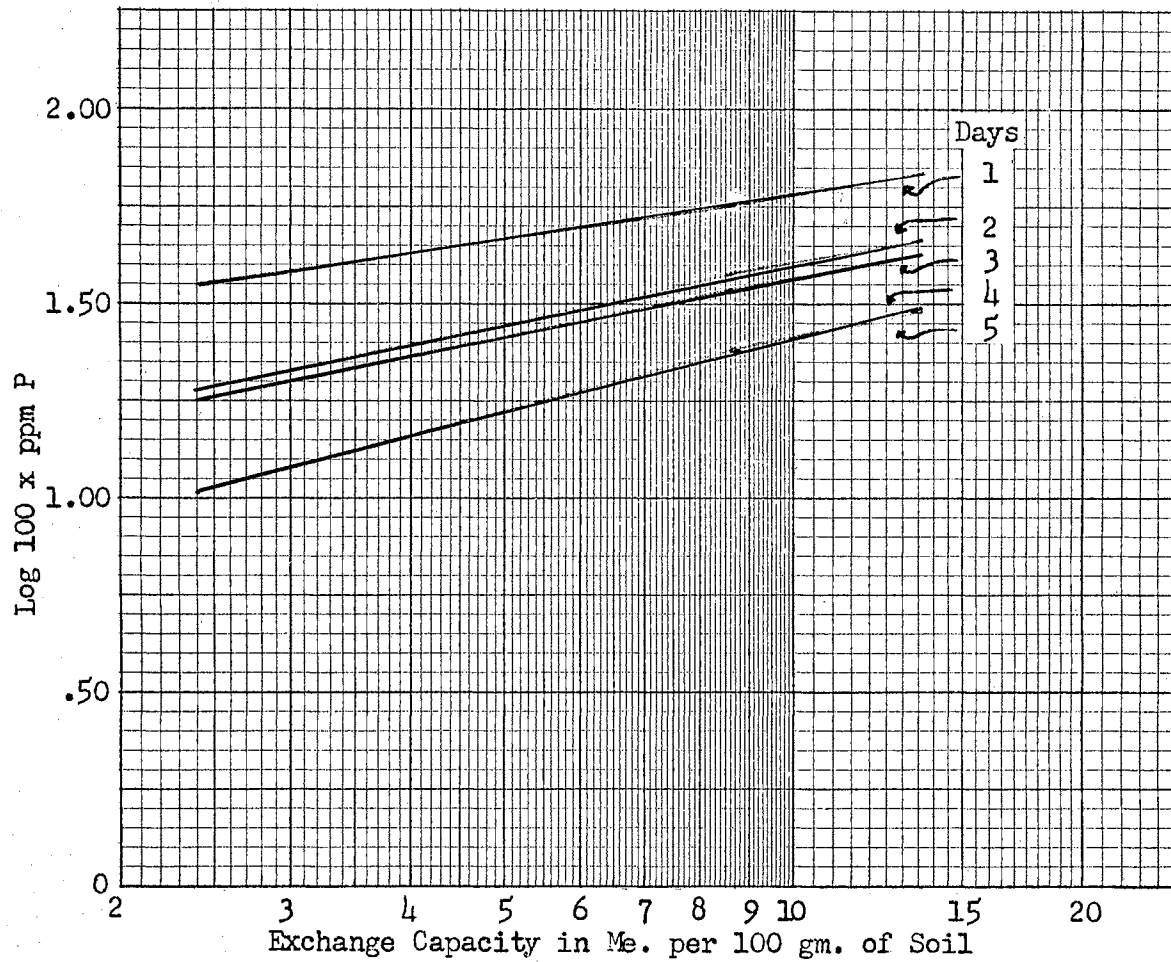
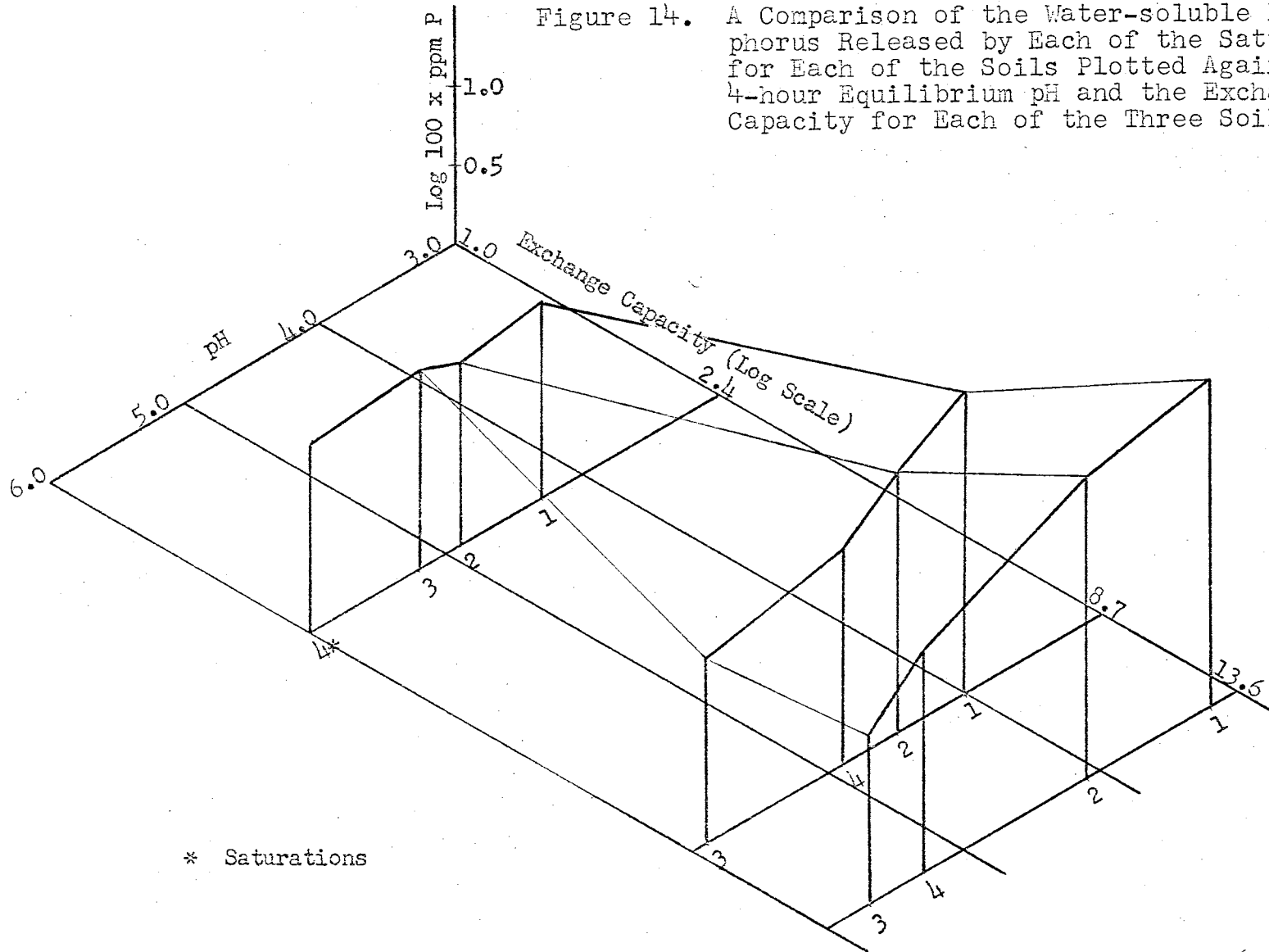


Figure 13. Release of Phosphorus from Each of the Three Soils by Days Plotted Against Exchange Capacity of the Soils.

Figure 14. A Comparison of the Water-soluble Phosphorus Released by Each of the Saturations for Each of the Soils Plotted Against the 4-hour Equilibrium pH and the Exchange Capacity for Each of the Three Soils.



* Saturations

from rock phosphate. The pH values at the 4-hour equilibrium for each of the soils at each of the base saturation levels used gave straighter phosphorus release curves and curvature was about the same for both sets of pH values.

Repeated leaching with water of three soils of different exchange capacity, each adjusted to four levels of percent base saturations, indicated that there is a close relationship between exchange capacity, percent base saturation, pH and the amount of phosphorus released from rock phosphate.

SUMMARY AND CONCLUSIONS

Portions of three soils with different exchange capacities were treated to obtain 35, 55 and 75% base saturation. Rock phosphate at the rate of 1500 pounds per acre was mixed with each of the soils at the three prepared saturations and with the "normal" soil. The soils and rock phosphate were wetted for three days, dried and ground to pass a 20-mesh sieve. Five grams of each of the 12 samples were mixed with 20 grams of fine acid-leached sand and layered in leaching tubes over a fine sand cushion and covered with a layer of sand. Four replications, each containing all three soils at the four saturations, were leached five successive times with 100 ml. of distilled water at 30-minute intervals daily for six successive days. The leachates were filtered and phosphorus determinations made with ammonium molybdate and stannous chloride.

The calcium content of the leachates was determined in the first and last leaching of the first day for two of the replications. Through the aid of statistics the release pattern of water-soluble phosphorus was determined between successive days and successive daily leachings, different base saturations and the 3-day equilibrium pH.

The release curves of phosphorus between days and between successive daily leachings expressed as logs of ppm of water-soluble phosphorus for the three soils produced straighter lines and greater linear sums of squares when the intervals between days and successive daily leachings were logarithmic

rather than linear; soil 3 with daily successive leachings was an exception.

The pH of the soil and rock phosphate mixture at the end of the 3-day equilibrium was better correlated with water-soluble phosphorus release than the percent base saturation.

The phosphorus from the rock phosphate was apparently released by the acidic action of the clay exchange complex of the soils studied.

There was a close relationship between the exchange capacity, percent base saturation, pH of the soils of the experiment and the amount of phosphorus released from rock phosphate.

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A P P E N D I X

TABLE 10
ANALYSIS OF VARIANCE, SOIL 1 (NORGE)

Source	df	(df)	M. S.	(M. S.)	F
Total	399				
Reps	3		0.62795		
Days	4				
Linear in Log Days		(1)		7.05389 **	357.88
Curvature in Log Days		(3)		0.09383 **	4.76
Leachings <u>1/</u>	4				
Linear in Log Leachings		(1)		18.66672 **	947.05
Curvature in Log Leach.		(3)		0.04027	2.04
Saturation	3				
(% Base Saturation Level)					
N Vs (S ₁ + S ₂ + S ₃)		(1)		2.64864	
Linear in Log Base Sat.		(1)		26.89710 **	1364.64
Curvature in Log Base Sat.		(1)		2.35074 **	119.27
Saturation	3				
(pH of N, S ₁ , S ₂ , S ₃)					
N Vs (S ₁ + S ₂ + S ₃)		(1)		2.64864	
Linear in pH of					
S ₁ , S ₂ , S ₃		(1)		29.24505 **	1483.60
Curvature in pH of					
S ₁ , S ₂ , S ₃		(1)		0.00279	0.14
D x L	16		0.02237		1.13
D x S	12		0.05234 **		2.66
L x S	12		0.03564 *		1.81
L x D x S	48		0.005153		0.26
Error	297		0.01971		

1/ Consecutive Daily Leachings.

** Significant difference at the 1% level.

* Significant difference at the 5% level.

TABLE 11
ANALYSIS OF VARIANCE, SOIL 2 (BOWIE)

Source	df	(df)	M. S.	(M. S.)	F
Total	399				
Reps	3		0.935400		
Days	4				
Linear in Log Days		(1)	15.41306	**	298.00
Curvature in Log Days		(3)	0.30429	**	6.88
Leachings <u>1/</u>	4				
Linear in Log Leachings		(1)	52.19796	**	1009.24
Curvature in Log Leach.		(3)	1.78934	**	34.60
Saturation	3				
(% Base Saturation Level)					
N Vs (S ₁ + S ₂ + S ₃)		(1)	0.11429		
Linear in Log Base Sat.		(1)	0.00096		0.02
Curvature in Log Base Sat.		(1)	0.56805	**	10.98
Saturation	3				
(pH of N, S ₁ , S ₂ , S ₃)					
N Vs (S ₁ + S ₂ + S ₃)		(1)	0.11429		
Linear in pH of S ₁ , S ₂ , S ₃		(1)	0.00873		0.17
Curvature in pH of S ₁ , S ₂ , S ₃		(1)	0.56028	**	10.83
D x L	16		0.16128	**	3.12
D x S	12		0.30823	**	5.96
L x S	12		0.12908	**	2.50
L x D x S	48		0.01711		0.33
Error	297		0.05172		

1/ Consecutive Daily Leachings

** Significant difference at the 1% level.

* Significant difference at the 5% level.

TABLE 12
ANALYSIS OF VARIANCE, SOIL 3 (WILSON)

Source	df	(df)	M. S.	(M. S.)	F
Total	399				
Reps	3		0.309767		
Days	4				
Linear in Log Days		(1)		6.73735 **	231.52
Curvature in Log Days		(3)		0.07646	2.63
Leachings <u>1/</u>	4				
Linear in Log Leachings		(1)		19.92642 **	684.76
Curvature in Log Leach.		(3)		0.13744 **	4.72
Saturation	3				
(% Base Saturation Level)					
N Vs ($S_1 + S_2 + S_3$)		(1)		6.50315	
Linear in Log Base Sat.		(1)		46.97864 **	1614.39
Curvature in Log Base Sat.		(1)		11.88601 **	408.45
Saturation	3				
(pH of N, S_1, S_2, S_3)					
N Vs ($S_1 + S_2 + S_3$)		(1)		6.50315	
Linear in pH of					
S_1, S_2, S_3		(1)		54.47181 **	1871.88
Curvature in pH of					
S_1, S_2, S_3		(1)		4.39285 **	150.96
D x L	16		0.02493		0.86
D x S	12		0.27163 **		9.33
L x S	12		0.04859		1.67
L x D x S	48		0.01158		0.40
Error	297		0.02910		

1/ Consecutive Daily Leachings.

** Significant difference at the 1% level.

* Significant difference at the 5% level.

TABLE 13

CALCIUM IN PPM CONTAINED IN LEACHATES

Soil	Saturation	Rep 2, 0 Day		Rep 4, 0 Day	
		Leach 1	Leach 5	Leach 1	Leach 5
1	1	0.8	0	0.5	0.2
	2	2.5	0	0.8	0.2
	3	0.8	0	0.3	0
	4	2.5	0.2	0.4	0.
2	1	0.8	0	0.2	0.2
	2	1.7	0	0.	0.
	3	1.7	-	0.	0
	4	1.7	0	0.2	0
3	1	0.8	0.5	0.2	0
	2	0	0.7	0.	0
	3	0.8	0.7	0.2	0
	4	0.8	0	0.2	0

PROFILE DESCRIPTION OF NORGE SANDY LOAM (SOIL 1)

The soil sample was taken from the center of series 1800 and the description was made at an adjacent site on series 1600 of the Agronomy Farm at Perkins, Oklahoma. The sampling and description sites were located in the SE $\frac{1}{4}$ of the SW $\frac{1}{4}$ of the NW $\frac{1}{4}$ of Section 36, Township 18 North and Range 2 East. This site developed on the long, gentle convex slopes between the farm's lower and upper elevation. Surface gradients about 2 $\frac{1}{2}$ percent. The sample site has been in continuous wheat for 20 years.

The soil profile is described as follows:

- | | | |
|------------------|--------|--|
| A _{1p} | 0-7" | Brown (7.5 YR 5/3; 4/2, moist) silt loam; weak medium granular; friable; permeable; pH 7.0; grades shortly to layer below. |
| A ₁ | 7-11" | Dark-brown (6.5 YR 4/3; 3/2, moist) silt loam; moderate medium granular; friable; porous and permeable; pH 6.5; many worm holes and pockets of worm casts; many fine pin holes; grades to the layer below. |
| B ₁ | 11-17" | Brown (7.5 YR 5/3; 4/2, moist) clay loam; moderate medium granular; friable to firm; hard when dry; permeable; pH 6.5; many pin holes and worm casts; grades to the layer below. |
| B ₂₋₁ | 17-26" | Reddish-brown (6 YR 5/5; 4/5, moist) light sandy clay faintly specked with yellowish-red; weak coarse prismatic and weak medium subangular blocky; firm; hard when dry; pH 6.5; occasional black concretions; grades to the layer below. |
| B ₂₋₂ | 26-36" | Reddish-yellow (7.5 YR 6/6; 5/5, moist) light sandy clay streaked with about 10% yellowish-red and strong brown; weak prismatic and weak medium subangular blocky; firm; hard when dry; |

pH 6.5; occasional fine pores, fine black concretions and ferruginous films; becomes more sandy in the lower portion and grades to the layer below.

- B₃ 36-44" Like the layer above but slightly less compact and sandy clay loam; pH 6.5; grades to the layer below.
- C₁ 44-60" Reddish-yellow (7.5 YR 6/6; 5.5/6, moist) heavy very fine sandy loam; friable; permeable; pH 6.5; contains a few seams of sandy clay loam, occasional black concretions and a few ferruginous films; grades to the layer below.
- C₂ 60-84" Reddish-yellow (6.5 YR 7/6; 6/6, moist) very fine sandy loam with occasional yellowish-red sandy clay loam seams; permeable; pH 7.0; occasional medium black concretions and ferruginous films. In the lower part there are seams of more compact sandy clay with dark reddish-brown coatings which crush yellowish-red. This material is old alluvium.

Described by Harry Galloway with modifications by Roy Smith (13).

PROFILE DESCRIPTION OF BOWIE LOAMY FINE SAND (SOIL 2)

A soil sample was taken from a site one mile west of Bentley in Atoka County SW $\frac{1}{4}$ of Section 7, Township 4 South, Range 12 East. This is in gently sloping erosional upland, which has a convex surface and a gradient of 1 $\frac{1}{2}$ percent. Corn was grown on this land in 1956.

The soil profile is described as follows:

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|-----------------|--------|--|
| A _{1p} | 0-6" | Light gray (10 YR 8/2; 5/2, moist) loamy fine sand; weak granular and friable; permeable; grades to the layer below; pH 6.2. |
| A ₂ | 6-10" | Light brown (7.5 YR 6/4; 5/4, moist) light fine sandy loam; nearly structureless, porous and permeable; rapidly permeable; grades thru a thin reddish-brown sandy clay loam transition to the layer below. |
| B ₂ | 10-24" | Reddish-brown (4 YR 5/4; 4/4, moist) sandy clay with weak medium subangular blocky firm; hard when dry; many root holes and fine channels; grades into the layer below. |
| C ₁ | 24-38" | Red sandy clay loam with thin seams of partly weathered reddish sandstone; occasional root holes and channels; ferruginous films; grades into the layer below. |
| D ₁ | 38-40" | Red (10 R 4/6) soft, fine-grained sandstone which is streaked in the interior or cleavage planes with black films. This sandstone is thinly banded and contains some silty shale. |

Described by Harry Galloway (16).

PROFILE DESCRIPTION OF WILSON SILT LOAM (SOIL 3)

A soil sample was taken from a site three-fourths mile southwest of Bokchito in Bryan County. The sampling site was located in the NW $\frac{1}{4}$ of the NW $\frac{1}{4}$, Section 28, Township 6 South and Range 11 East. This site is on convex sloping erosional upland with a gradient of two percent. There is a scattering of 1" to 3" quartzite pebbles on the surface. Oats was the last crop to be grown on this land.

The soil profile is described as follows:

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|------------------|--------|--|
| A _{1p} | 0-8" | Dark grayish-brown (10 YR 4/2; 3/2, moist) silt loam; weak granular; friable; permeable; pH 5.4; many fine roots; rests sharply on the layer below. |
| B ₁ | 8-11" | Dark grayish-brown (10 YR 4/2) silty clay loam slightly mottled with a brownish-yellow; friable; weak medium subangular blocky; some roots and worm casts; pH 6.0; grades into horizon below. |
| B ₂₋₁ | 11-22" | Grayish-brown (10 YR 4/2) clay mottled with ten to twenty percent reddish-brown; compound weak coarse prismatic and moderate medium blocky firm; very hard dry; medium crumbly moist; pH 6.0; grades into horizon below. |
| B ₂₋₂ | 22-42" | Grayish-brown (10 YR 4/2) clay; weak blocky; sticky and plastic wet; very hard dry; fine roots to lower depths; clay films on perpendicular planes; grades to horizon below. |
| B _{3c} | 42-54" | Grayish-brown (10 YR 5/3; 4/3, moist) crumbly clay mottled with yellowish-brown and specked with yellowish-red; occasional black concretions; and calcium carbonate accumulations; a few pockets of gypsum crystals. |

Described by Harry Galloway (16).

Vita

Chauncey Cox Schaller

Candidate for the Degree

of

Master of Science

Thesis: THE EFFECT OF BASE SATURATION, pH AND EXCHANGE CAPACITY ON THE RELEASE OF PHOSPHORUS FROM ACID SOILS CONTAINING ROCK PHOSPHATE.

Major: Agronomy

Biographical:

Personal data: Born Jan. 15, 1921, at Clark, Pennsylvania, son of Chauncey W. and Emma E. Schaller.

Education: Graduated from New Castle High School, New Castle, Pennsylvania, 1939. Undergraduate work at Oklahoma Agricultural and Mechanical College of Stillwater, Oklahoma, 1939-1942, 1946-1947. Graduate study at Oklahoma State University, 1958-1959.

Experience: Farm labor during the summer and vacations, 1935-1939. U. S. Army 1942-1945. Farm labor summer 1946. Soils laboratory technician, part time, 1946. Wilson & Company 1947-1948. S. R. Noble Foundation, Ardmore, 1948-1958. Graduate research assistant, 1958-1959, Oklahoma State University.

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Date of Final Examination: September, 1959.