A STUDY OF THE EFFECT OF MINERAL PHOSPHATES UPON THE ORGANIC PHOSPHORUS CONTENT OF ORGANIC SOILS

By

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AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
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ABSTRACT

A Study of the Effect of Mineral Phosphates
Upon the Organic Phosphorus Content of Organic Soils

Laboratory studies were conducted to investigate the effect of mineral phosphates upon the organic phosphorus content of eight organic soils. Soil types represented were Carlisle Muck, Everglades Peat, Houghton Muck, Istopoka Peat and Rifle Peat. Six of the samples were obtained in Michigan and two from Florida. Monocalcium phosphate was applied to each soil at the following rates: 100, 200, 400, 800 and 1600 pounds of P_2O_5 per acre. Unphosphated samples were left as controls. To determine if mineralization was as extensive as shown by soil analyses, available phosphorus and soluble nitrogen were determined before and after a four-month incubation period. The effect of sterilization, temperature and moisture upon the mineralization of organic phosphorus in Houghton Muck was also determined.

Samples were incubated for a period of four months and the amount of organic phosphorus determined, by the method of Pearson, at the end of two, three and four months.

No "fixation" of mineral phosphate as organic phosphorus occurred, but mineralization of the original organic phosphorus did occur.

In general the greater the amount of monocalcium phosphate added the more rapid was this rate of mineralization over a period of four months. Generally the rate of mineralization was rapid the first two months and somewhat slower during the last two months.

The percentage increase in available phosphorus after four months

incubation ranged from 37.6 to 421 percent.

The percentage increase of soluble nitrogen after four months incubation ranged from 21.4 to 143.5 percent.

Temperature and moisture were shown to be two factors affecting mineralization of organic phosphorus. The mineralization of organic phosphorus continued after the soil was sterilized with mercuric chloride.

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INTRODUCTION

Although much research has been devoted to organic phosphorus compounds, relatively little information is available regarding the influence of mineral phosphates upon the organic phosphorus of organic soils.[1] Preliminary work on an organic soil of Michigan indicated that the addition of 2200 pounds of P_2O_5 per acre, as superphosphate, over a period of eleven years did not appreciably change the organic phosphorus content from that of the soil in the virgin condition (See Table VII, Appendix page 27).

This investigation was planned to study the effect of mineral phosphate upon the organic phosphorus content of organic soils.

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[1] Organic soils are those with more than 20 percent organic matter, one foot or more in thickness and formed under conditions of poor drainage.

REVIEW OF LITERATURE

The first work on soil organic phosphorus dates back 110 years to experiments in Europe, when Mulder (15)[2] was unable to prepare phosphorus-free fractions of soil organic matter. The accumulation of knowledge concerning the methods of determination, amount, forms, transformations and importance of organic phosphorus has been traced by many authors, the most recent and comprehensive to date being that of Black and Goring (5).

Since the beginning of soil organic phosphorus studies there has been essentially only one general procedure for determining this important constitutient of the soil. It was arrived at by determination of the inorganic and total phosphorus before and after treatments designed to change organic phosphorus to inorganic forms, the amount of organic phosphorus being determined by difference. The method of Pearson (16,21) was used in this work. However, the procedure of Metha (14) may prove more adaptable to this type of work.

The amount of organic phosphorus varies within wide limits in different soils. Most of the organic phosphorus is found in the surface soil (5) and decreases gradually with depth. Soils derived from recent sediments or having pronounced horizon differentiation may present irregularities. The organic phosphorus constitutes from 30 to 85 percent (5,6,10,12) of the total soil phosphorus whereas in organic soils it may amount to 75 to 85 percent of the total (10).

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[2] Numbers in parentheses refer to literature cited.

Plant and animal tissue is the source of soil organic phosphorus, which should be the same form as that found in these tissues. Bower (6,7) stated that there are four forms of organic phosphorus present in the soil; nucleic acids, phytin and its derivatives, inisitol phosphate and the phospholipids which are present to a limited extent but do not seem to be very important. Black and Goring (5) listed five forms of organic phosphorus in the soil; phospholipids, nucleic acid, inisitol phosphates, "metabolic" phosphates and phosphoproteins. In investigations of the organic phosphorus compounds in the soil, attention has been limited to the first three groups. Dyer and Wrenshall (12) mentioned five organic phosphorus compounds which may be found in soils; phospholipids, nucleic acid, sugar phosphates and related compounds, phosphoproteins and phytin and its derivatives.

The availability of the different forms of organic phosphorus varies greatly (5,6,7,12,13,18). The unavailability of organic phosphorus is most likely a result, in part, of the formation of insoluble salts with polyvalent ions (5,13) and, in part, of adsorption by clays or organic constituents of the soil (5,7,18). Doughty (11) found that soluble phosphates become "fixed" by iron and aluminum in an acid peat soil. Bertramson (4) reported indications that phosphorus nutrition in plants is in the organic realm and the utilization of organic phosphorus depends upon the ease with which it can be converted to inorganic forms. He further stated that the availability of organic phosphorus is in part a biological phenomenon.

In most experiments it was found that the organic phosphorus was of little significance in plant nutrition until it was mineralized. Black and Goring (5) reported two types of evidence that mineralization takes place. The first is based upon changes in soils as a result of long continued treatment. Pearson, et al (17) and Thompson and Black (22) noted that the content of organic phosphorus is usually lower in cultivated soils than in comparable virgin soils. The other type of evidence is based upon laboratory experiments conducted over a relatively short period of time. Bower (7) discovered that where there was an increase in inorganic phosphorus, a corresponding decrease in organic phosphorus was noted. Pearson, et al (17) found that the organic phosphorus was incompletely mineralized in a period of one month. Thompson and Black (22) stated that all of the soil organic phosphorus was mineralized in a period of seven days at 150° C.

The rate of mineralization of organic phosphorus depends upon several factors. Thompson and Black (22) found that it was correlated positively with the amounts of organic carbon and nitrogen in the soil. They also found that the pH of the soil, the type of organic phosphorus and the kind of soil affected rate of mineralization. Pearson, et al (17) noted that increases in pH increased the rate of mineralization of organic phosphorus, microbiological fixation decreased the rate and the presence of lignin possibly reduced it. Dyer and Wrenshall (13) stated that the liming of acid soils might be expected to hasten the availability of organic phosphorus for the plant. Barbarian and Bonner (3) noted that at 25° C organic phosphorus failed to form in the potato. However, Bower (7), Thompson and Black (22) discovered that mineralization increased with increasing temperature especially above 25° to 30° C. Thompson and Black (22) stated also that the hot sun increased the soluble phosphorus content of the soil.

Rogers (19) showed that toluene was an effective sterilization agent in stopping evolution of CO_2 from the soil. Many workers have found that plant roots produced several enzymes. Rogers (19) determined that soils produced enzymes which caused dephosphorylation of organic phosphorus compounds. He found that catalysts in the soil were effective in mineralization of the soil organic phosphorus after effective sterilization with toluene. These data suggest that the conversion of organic phosphorus to mineral forms is not entirely a function of microbiological activity in the soil.

EXPERIMENTAL PROCEDURE

Eight surface soil samples of virgin organic soil were used in this study. Six were from Michigan and two were from Florida. The location of these soils as well as some of their chemical properties are given in Table I. The soils were air dried, passed through a two millimeter sieve and the moisture content determined. The pH was determined with the glass electrode and organic phosphorus was determined by the method of Pearson (15).

One hundred gram samples were incubated for four months after they received monocalcium phosphate at rates equivalent to 100, 200, 400, 800 and 1600 pounds of P_2O_5 per acre. Unphosphated samples were incubated for the same period of time for controls.

During incubation the samples were maintained at approximate moisture equivalent and at a temperature of 80° F. Samples were analyzed for organic phosphorus at the end of two, three and four months. At the end of four months the available inorganic phosphorus and the soluble nitrogen content were determined on samples that had received 400 pounds of P_2O_5 per acre. The results of all determinations are reported in Tables II through V inclusive.

In the second phase of the study, two samples of soil 7 (Houghton Muck) were used. Sample 7A had been stored in a moist condition for four months while sample 7B was obtained from the field in a frozen condition. These soils were prepared as were those in the first phase of the experiment. An application of 400 pounds of P_2O_5 per acre was

TABLE I

THE SOIL TYPE, LOCATION AND SOME CHEMICAL PROPERTIES OF EIGHT ORGANIC SOILS

Soil number	Soil type	Location	pH	PPM of phosphorus: Inorganic	PPM of phosphorus: Organic	PPM of phosphorus: Total	Percent organic phosphorus
1	Rifle Peat	Livingston Co., Mich.	3.6	320	600	920	65.2
2	Rifle Peat	Clinton Co., Mich.	4.0	320	320	640	50.0
3	Rifle Peat	Lapeer Co., Mich.	4.2	380	420	800	52.5
4	Istopoka Peat	Highlands Co., Fla.	4.7	1340	700	2040	34.3
5	Everglades Peat	Indian River Co., Fla.	5.0	240	480	720	66.7
6	Rifle Peat	Calhoun Co., Mich.	5.1	340	540	880	61.4
7	Houghton Muck	Clinton Co., Mich.	6.3	460	420	880	47.7
8	Carlisle Muck	Clinton Co., Mich.	7.2	560	640	1200	53.3

made to each sample except the control. These samples were incubated for four months with the following treatments: (1) sterilization, (2) constant temperature of 45° F., (3) constant temperature of 55° F., (4) temperature of 80° F., (5) constant moisture at 30 percent, (6) constant moisture at moisture equivalent, and (7) constant moisture at saturation. All samples except those in treatments 2 and 3 were held at room temperature, and all treatments except those in treatments 5 and 7 were held at moisture equivalent. All samples were kept moist with distilled water except those in treatment 1, which were moistened with 1:10,000 solution of mercuric chloride. Results of this experiment are given in Table VI.

In this procedure one percent variation in transmission on the colorimeter, when applied to the standard curve, resulted in a difference of 20 ppm on a soil basis and possibly accounted for, in part, the variability in the results obtained.

METHODS OF CHEMICAL ANALYSIS

Organic Phosphorus

Weigh out 0.5 grams of organic soil and place in a small beaker. Add 20 ml. of 0.1 N hydrochloric acid to each and let stand for several minutes. Place on a hot plate for five minutes. Filter through phosphorus free filter paper and wash with small portions of 0.1 N hydrochloric acid until free of calcium. Make this acid filtrate to volume in a 200 ml. volumetric flask and save. Transfer the acid washed soil with the filter paper to a 500 ml. Erlenmeyer flask graduated at 400 ml.. Add 200 to 300 ml. of 0.5 N ammonium hydroxide and shake thoroughly until the filter paper is shredded. Rinse stopper and the sides of the flask and make up to volume with 0.5 N ammonium hydroxide. Fit flask with a bunsen stopper and digest at 90° C. for 18 hours. Cool flask to room temperature in running water bath and add five grams of ammonium chloride, adjust to 400 ml. mark, and shake thoroughly, and allow to stand until suspended material settles out. Decant through phosphorus-free filter paper and discard the filtrate as long as suspended material can be observed. Place a 10 ml. aliquot of the clear filtrate in each of two thoroughly weathered 100 ml. beakers and add five ml. of the acid extract. One aliquot is used for the determination of the total phosphorus and one for the determination of the inorganic phosphorus. For inorganic phosphorus determination add four ml. of 1.0 N sulfuric acid and 0.025 grams of carbon black to one of the aliquots and swirl to mix thoroughly. Filter, rinse the beaker and wash the paper five times with small portions of water (do not fill the funnel more than one-half full). Dilute the decolorized filtrate to 40 ml. with water, add one drop of p-nitrophenol and add 1:1 ammonium hydroxide dropwise until the solution turns yellow. Then add 1.0 N sulfuric acid drop by drop until the color disappears. Add 2 ml. of ammonium molybdate and adjust volume to 50 ml.. To develop the color add three drops of stannous chloride and let stand for 40 minutes. Then read the percent light transmission on a photoelectric colorimeter, using a red (650 $m\mu$) filter. Compare with standards which have been made and treated the same as the samples (except add 0.12 grams of ammonium chloride to each 50 ml. standard). For total phosphorus determination evaporate the second aliquot to dryness with one ml. of 10 percent magnesium nitrate (phosphorus-free). Ignite in muffle furnace at 600° C until white ash is formed. Dissolve in four ml. of 1.0 N sulfuric acid and dilute to 40 ml. with water. Adjust acidity and proceed as before. Organic phosphorus is calculated as the difference between the total phosphorus and the inorganic phosphorus.

Soluble Nitrogen

Transfer 25 grams of soil to a 500 ml. flask and add 300 ml. of four percent potassium chloride. Shake at intervals and let stand overnight. Filter off 200 ml. of liquid and place in an 800 ml. Kjeldahl flask. Make alkaline with six to eight ml. of concentrated sodium hydroxide solution. Distill into 25 ml. of four percent boric acid solution and continue distillation until 25 ml. remains in the Kjeldahl flask. To determine the ammonia add three drops of brom-phenol-blue to the boric acid — distillate solution and titrate using standardized sulfuric acid. Calculate the amount of ammonia present.

For the nitrate nitrogen determination make the solution left in the Kjeldahl flask up to approximately the original volume with distilled water. Add one gram of Devarda's alloy. Distill slowly into a four percent boric acid solution. Add indicator and titrate as before. Calculate the amount of nitrates. Then calculate the milligrams of soluble nitrogen in 100 grams of air dry soil.

Available Phosphorus

Adsorbed phosphorus. Weigh one gram of air dried soil into a glass container and add 10 ml. of extracting solution (0.03 N NH_4F and 0.025 N HCl). Stopper and shake for one minute, filter through phosphorus-free filter paper. Then add six drops of ammonium molybdate-hydrochloric acid solution and three drops of stannous chloride — hydrochloric acid solution. After five or six minutes read on a photoelectric colorimeter using a red (650 mμ) filter and compare with known standards.

Acid soluble and adsorbed phosphorus. Weigh one gram of air dried soil into a glass container and add 10 ml. of extracting solution (0.03 N NH_4F and 0.1 N HCl). Stopper and shake for forty seconds and filter through phosphorus-free filter paper. Then develop color and proceed as above.

The acid soluble and adsorbed phosphorus minus the adsorbed phosphorus gives the acid soluble phosphorus. The available phosphorus is the sum of the acid soluble and adsorbed phosphorus.

DISCUSSION OF EXPERIMENTAL RESULTS

The eight organic soils used in this study varied in organic phosphorus content from 320 to 700 ppm and in percentage of phosphorus in organic form from 34.3 to 66.7 percent. A direct relationship was found to exist between the amount of total phosphorus and soil organic phosphorus. In general the higher the total phosphorus the higher was the organic phosphorus content. Soils 5 and 7 were exceptions.

No relationship was found to exist between the actual amount of organic phosphorus present and the percent of the total phosphorus in organic form in these eight soils.

The effect of mineral phosphates on the level of organic phosphorus varied between soils, but the trend was the same in all soils. In order to avoid repetition the data from the eight soils were averaged and are presented in Table II. The data from all eight soils are presented separately in tables and graphs which are found in the appendix. The results of the incubation for a specific soil, number 6, are shown in Table III. In general the data are similar to those obtained by averaging the results of incubation for the eight soils (Table II).

In soil 6 mineralization was very rapid during the first two months in all samples except the two with the highest rates of phosphorus application. In these samples only 30 and 22 percent, respectively, of the organic phosphorus had been mineralized by the end of the second month.

TABLE II

THE AVERAGE RESULTS OF FOUR MONTHS INCUBATION UPON THE ORGANIC PHOSPHORUS CONTENT OF EIGHT ORGANIC SOILS[1]

Monocalcium phosphate applied	PPM organic phosphorus		
Pounds P_2O_5 per acre	2 months	3 months	4 months
None	242	245	152
100	335	237	150
200	236	140	140
400	240	177	135
800	372	100	35
1600	300	100	25

[1] The average original organic phosphorus content of these soils was 515 ppm.

During the third month the rate of mineralization was slow or at a standstill in three of the samples and was rapid in the other three. It continued at a rapid rate, as shown by Table III, in the samples treated at the 100, the 800 and the 1600 pound rates of P_2O_5.

At the end of four months, mineralization was complete in two samples, where 100 and 1600 pounds respectively of P_2O_5 were added. The other samples all contained less than 50 ppm of organic phosphorus except the control which contained 100 ppm.

The data in Table II indicate that in these eight organic soils none of the added monocalcium phosphate was converted or "fixed" as organic phosphorus but that the addition of the phosphate actually caused an apparent mineralization of the organic phosphorus of the soil. In general the greater the amount of monocalcium phosphate added the more rapid was the rate of mineralization over a period of four months. During the first two months approximately one-half of the organic phosphorus was mineralized. Except in the case of the control sample, mineralization continued at a rapid rate during the third month. The rate increased again in the control, during the fourth month, but decreased slightly in all the remaining samples. The rate of mineralization was not the same as that reported (5,7,13,17,19) for organic phosphorus compounds added to the soil or for organic phosphorus compounds in the laboratory. The data show that the soil organic phosphorus behaves differently from organic phosphorus of other sources.

There was an increase, as shown in Table IV in available phosphorus (acid soluble plus adsorbed) in all soils except 7 and 8. This increase

TABLE III

THE RESULTS OF FOUR MONTHS INCUBATION UPON THE ORGANIC PHOSPHORUS CONTENT OF SOIL 6[1]

Monocalcium phosphate applied	PPM organic phosphorus		
Pounds P_2O_5 per acre	2 months	3 months	4 months
None	220	200	100
100	220	100	0
200	120	140	20
400	20	20	40
800	380	300	20
1600	420	40	0

[1] The original organic phosphorus content of this soil was 540 ppm.

ranged from 37.6 to 421 percent of that present before incubation. In soils 7 and 8 there was an increase in acid soluble phosphorus but a decrease in adsorbed phosphorus resulting in essentially no effect upon the sum of the two forms. In soils which were within the pH range of 4.0 to 5.0 inclusive the greatest increase in available phosphorus occurred. Those soils below this range showed less increase and in those above 5.1 there was no increase. The amount of adsorbed phosphorus decreased and the acid soluble phosphorus increased in the soils with pH above and below the range 4.0 to 5.1.

Table V shows there was an increase in total soluble nitrogen in all eight soils during four months incubation. The percentage increase varied from 21.4 to 143.5 percent. There was an increase in the soluble ammonia in all soils except soil 6. The soluble nitrates increased in soils 5, 6 and 7, decreased in soils 2, 3 and 4 and remained unchanged in soils 1 and 8. Nitrates increased in the pH range of 5.0 to 6.3 and decreased in the range 4.0 to 5.0. There is no apparent relationship between the percent increase in soluble nitrogen and the actual decrease in organic phosphorus content, however, the increase in soluble nitrogen suggests that mineralization of the organic phosphorus did take place as shown by the soil analyses. This conclusion is further strengthened by the data presented in Table IV which show an increase in available phosphorus in most of these soils.

The method of handling soil samples previous to and during incubation exerted an influence upon the rate of mineralization of organic phosphorus as shown in Table VI. These data show that saturation slowed

TABLE IV

THE EFFECT OF FOUR MONTHS INCUBATION UPON THE AVAILABLE PHOSPHORUS[1] CONTENT OF EIGHT ORGANIC SOILS

Soil		PPM of extracted phosphorus					
		Acid soluble		Adsorbed		Total	
number	pH	Before	After[2]	Before	After[2]	Before	After[2]
1	3.6	40	575	233	65	273	640
2	4.0	94	457	58	335	152	792
3	4.2	108	450	85	255	193	705
4	4.7	510	880	500	510	1010	1390
5	5.0	21	192	50	155	71	347
6	5.1	32	310	225	210	257	520
7	6.3	12	120	150	43	162	163
8	7.2	66	195	150	18	216	214

[1] Analyses by procedure of Bray and Kurtz (8).

[2] These soils incubated for four months with 400 pounds P_2O_5 per acre.

TABLE V

THE EFFECT OF FOUR MONTHS INCUBATION UPON THE TOTAL SOLUBLE NITROGEN CONTENT OF EIGHT ORGANIC SOILS

Soil number	pH	Milliequivalents ammonia in 100 grams of soil		Milliequivalents nitrate in 100 grams of soil		Milliequivalents of total nitrogen in 100 grams of soil	
		Before	After[1]	Before	After[1]	Before	After[1]
1	3.6	1.40	1.96	1.16	1.16	2.56	3.12
2	4.0	1.66	3.44	0.92	0.84	2.58	4.28
3	4.2	0.98	3.60	2.22	1.70	3.20	5.30
4	4.7	1.30	2.08	1.02	0.80	2.32	2.88
5	5.0	1.34	2.22	1.34	2.72	2.68	4.94
6	5.1	1.62	1.04	2.08	3.56	3.70	4.60
7	6.3	0.92	2.32	1.38	3.28	2.30	5.60
8	7.2	0.94	1.60	0.68	0.68	1.62	2.28

[1] These soils were incubated four months with 400 pounds of P_2O_5 per acre.

TABLE VI

THE EFFECT OF DIFFERENT TREATMENTS UPON THE MINERALIZATION OF ORGANIC PHOSPHORUS IN TWO SAMPLES OF SOIL 7

Treatment		PPM organic phosphorus, Time of incubation					
Temperature °F.	Moisture level	2 months 7A[1]	2 months 7B[2]	3 months 7A[1]	3 months 7B[2]	4 months 7A[1]	4 months 7B[2]
80[3]	Moisture equivalent	240	60	110	110	140	100
80[4]	Moisture equivalent	0	0	0	30	40	0
45	Moisture equivalent	220	60	0	20	0	0
55	Moisture equivalent	200	30	100	20	0	20
80	Moisture equivalent	220	140	30	0	60	20
80	30 percent	140	60	40	0	0	0
80	Moisture equivalent[5]	80	220	0	0	0	0
80	Saturation	220	55	120	50	0	80

[1] This sample was stored moist for four months before it was used.

[2] This sample was taken from the field in a frozen condition before it was used.

[3] This was the control sample. All other samples received 400 pounds of P_2O_5 per acre.

[4] This sample was sterilized with 1:10,000 solution of $HgCl_2$.

[5] Moisture added two times a week based upon the needs of this sample.

the rate of mineralization, but the data for the other moisture levels and the different temperatures were so variable that no definite conclusions could be made. This would indicate that conditions which favor microbiological activity in the soil induce more rapid rates of mineralization than those conditions which are unfavorable for such activity.

Where the soil had been sterilized with mercuric chloride, dephosphorylation of the soil organic phosphorus continued. This was possibly due to the presence of soil enzymes which continue to catalyze the process of mineralization even after the soil has been sterilized.

SUMMARY

The purpose of this investigation was to study the effect of mineral phosphates upon the organic phosphorus content of organic soils.

Eight virgin organic soils were obtained from various locations in Michigan and Florida. These soils were treated with different levels of monocalcium phosphate. The soils were incubated in the laboratory for a period of four months, at approximate moisture equivalent and 80° F.

Samples were analyzed at two, three and four months for organic phosphorus by the method of Pearson. All samples receiving 400 pounds of P_2O_5 per acre were analyzed for soluble nitrogen and available phosphorus.

A second phase of the experiment was run to determine the effect of temperature, moisture and sterilization upon the rate of mineralization of the organic phosphorus in Houghton Muck (soil 7).

Samples were maintained at constant temperatures of 45° F. and 55° F. Constant moisture levels of 30 percent, moisture equivalent and saturation were maintained. Sterilization was with mercuric chloride, a common sterilization agent in the laboratory.

Samples were analyzed at two, three and four months for organic phosphorus.

The following observations were made:

1. When monocalcium phosphate was added to organic soils, mineralization of the soil organic phosphorus occurred.

2. The greater the amount of monocalcium phosphate added, the more rapid was the rate of mineralization over a period of four months.
3. About one-half of the organic phosphorus was mineralized during the first two months.
4. Mineralization continued rapidly during the third month in all samples except the control.
5. The rate increased again in the control during the fourth month, but decreased slightly where monocalcium phosphate had been added.
6. The rate of mineralization for soil organic phosphorus in eight organic soils was not the same as that reported for organic phosphorus compounds added to the soil or for organic phosphorus compounds in the laboratory. Soil organic phosphorus behaves differently from organic phosphorus of other sources.
7. The available phosphorus content increased in six of the eight soils. The increase ranged from 37.6 to 421 percent.
8. The soluble nitrogen content of all eight soils increased. The increase ranged from 21.4 to 143.5 percent.
9. Methods of handling soil samples previous to and during incubation exerted an influence upon the rate of mineralization. For this reason all samples to be used in incubation studies should be similarly handled before incubation.
10. Saturation with water slowed the rate of mineralization.
11. Conditions which favored microbiological activity in the soil induced more rapid rates of mineralization than those conditions which were unfavorable for such activity.

12. Mineralization occurred even though the soil was sterilized. This was due possibly to the presence of soil enzymes which continued to catalyze the process.

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APPENDIX A

TABLE VII

THE EFFECT OF SUPERPHOSPHATE UPON THE ORGANIC PHOSPHORUS CONTENT OF A MICHIGAN ORGANIC SOIL[1]

Treatment	Pounds P_2O_5 per acre[2]	PPM organic phosphorus
Virgin	None	320
Cultivated	None	360
Superphosphate	1100	360
Superphosphate	2200	400

[1] This soil is Houghton Muck which had a pH of 6.3.

[2] Applied over a period of eleven years (1941-1951).

TABLE VIII

THE RESULTS OF FOUR MONTHS INCUBATION UPON THE ORGANIC PHOSPHORUS CONTENT OF SOIL 1[1]

Monocalcium phosphate applied	PPM organic phosphorus		
Pounds P_2O_5 per acre	2 months	3 months	4 months
None	220	120	60
100	220	200	0
200	140	20	80
400	20	140	200
800	20	240	0
1600	0	320	0

[1] This soil originally contained 600 ppm of organic phosphorus.

TABLE IX

THE RESULTS OF FOUR MONTHS INCUBATION UPON THE ORGANIC PHOSPHORUS CONTENT OF SOIL 2[1]

Monocalcium phosphate applied	PPM organic phosphorus		
Pounds P_2O_5 per acre	2 months	3 months	4 months
None	320	160	60
100	320	260	40
200	310	180	40
400	300	340	80
800	140	0	0
1600	160	240	0

[1] This soil originally contained 320 ppm of organic phosphorus.

TABLE X

THE RESULTS OF FOUR MONTHS INCUBATION UPON THE ORGANIC PHOSPHORUS CONTENT OF SOIL 3[1]

Monocalcium phosphate applied	PPM organic phosphorus		
Pounds P_2O_5 per acre	2 months	3 months	4 months
None	300	460	220
100	260	280	180
200	240	160	40
400	200	140	0
800	440	0	60
1600	280	0	0

[1] This soil originally contained 420 ppm of organic phosphorus.

TABLE XI

THE RESULTS OF FOUR MONTHS INCUBATION UPON THE ORGANIC PHOSPHORUS CONTENT OF SOIL 4[1]

Monocalcium phosphate applied	PPM organic phosphorus		
Pounds P_2O_5 per acre	2 months	3 months	4 months
None	80	260	220
100	620	260	360
200	740	280	240
400	480	120	380
800	520	100	120
1600	560	0	0

[1] This soil originally contained 700 ppm of organic phosphorus.

TABLE XII

THE RESULTS OF FOUR MONTHS INCUBATION UPON THE ORGANIC PHOSPHORUS CONTENT OF SOIL 5[1]

Monocalcium phosphate applied	PPM organic phosphorus		
Pounds P_2O_5 per acre	2 months	3 months	4 months
None	300	180	80
100	400	300	240
200	0	140	220
400	220	60	340
800	460	140	80
1600	400	200	200

[1] This soil originally contained 480 ppm of organic phosphorus.

TABLE XIII

THE RESULTS OF FOUR MONTHS INCUBATION UPON THE ORGANIC PHOSPHORUS CONTENT OF SOIL 7[1]

Monocalcium phosphate applied	PPM organic phosphorus		
Pounds P_2O_5 per acre	2 months	3 months	4 months
None	300	280	280
100	200	200	80
200	140	220	380
400	280	160	0
800	420	20	0
1600	500	0	0

[1] This soil originally contained 420 ppm of organic phosphorus.

TABLE XIV

THE RESULTS OF FOUR MONTHS INCUBATION UPON THE ORGANIC PHOSPHORUS CONTENT OF SOIL 8[1]

Monocalcium phosphate applied	PPM organic phosphorus		
Pounds P_2O_5 per acre	2 months	3 months	4 months
None	200	300	200
100	440	300	300
200	200	0	100
400	400	440	40
800	600	0	0
1600	80	0	0

[1] This soil originally contained 640 ppm of organic phosphorus.

APPENDIX B

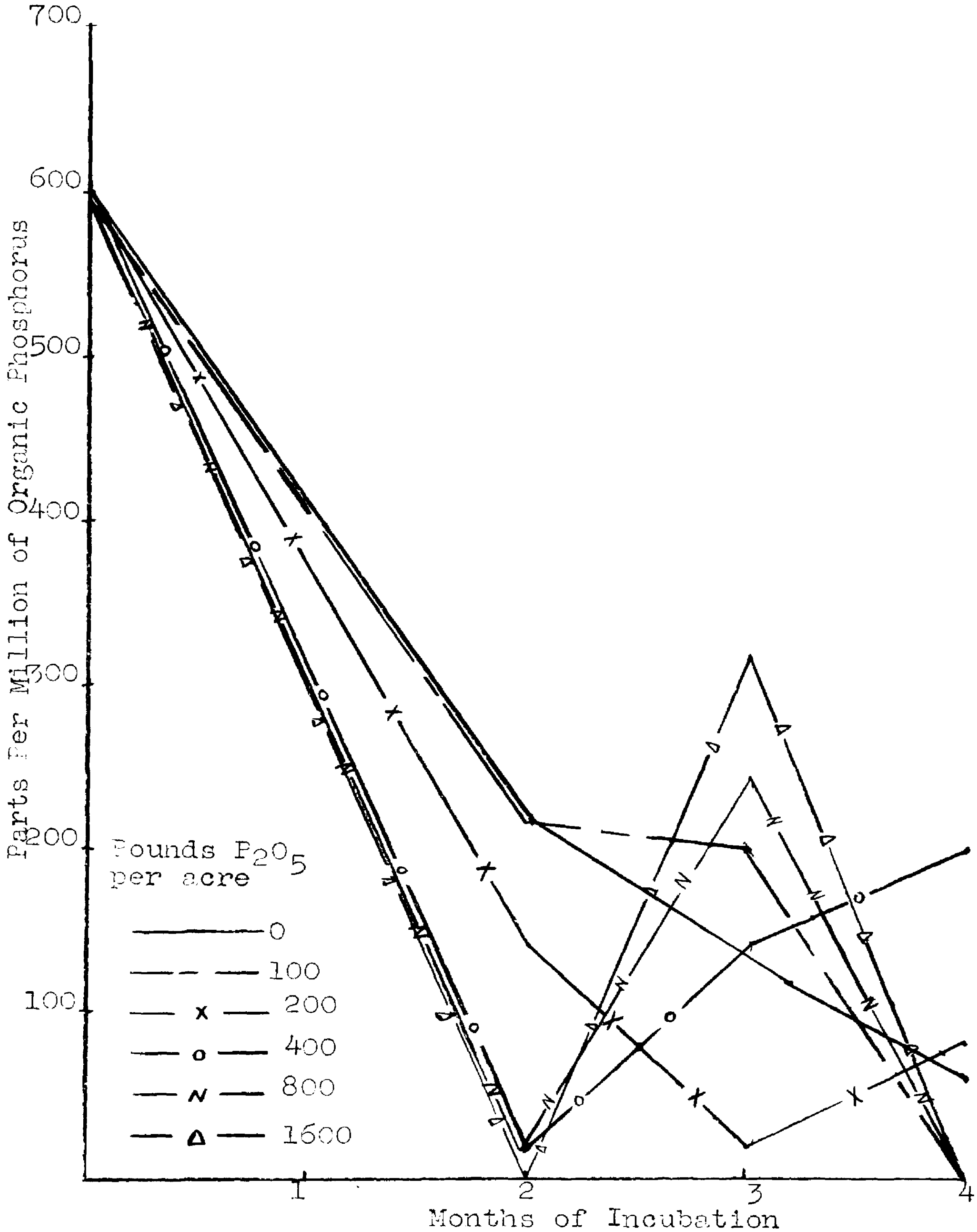

Fig. 1. The effect of $CaH_4(PO_4)_2$, applied at different rates, upon the mineralization of organic phosphorus in soil 1.

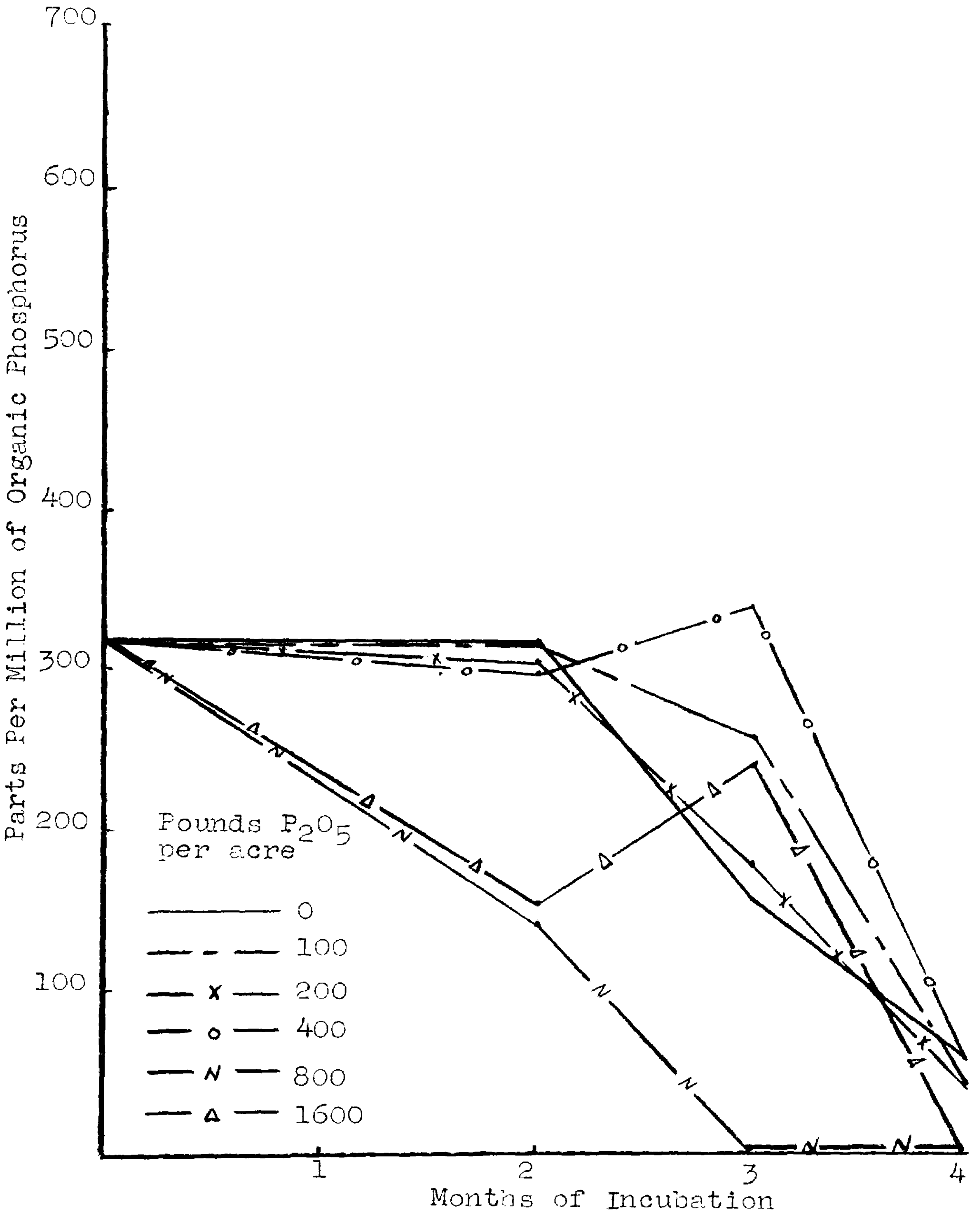

Fig. 2. The effect of $CaH_4(PO_4)_2$, applied at different rates, upon the mineralization of organic phosphorus in soil 2.

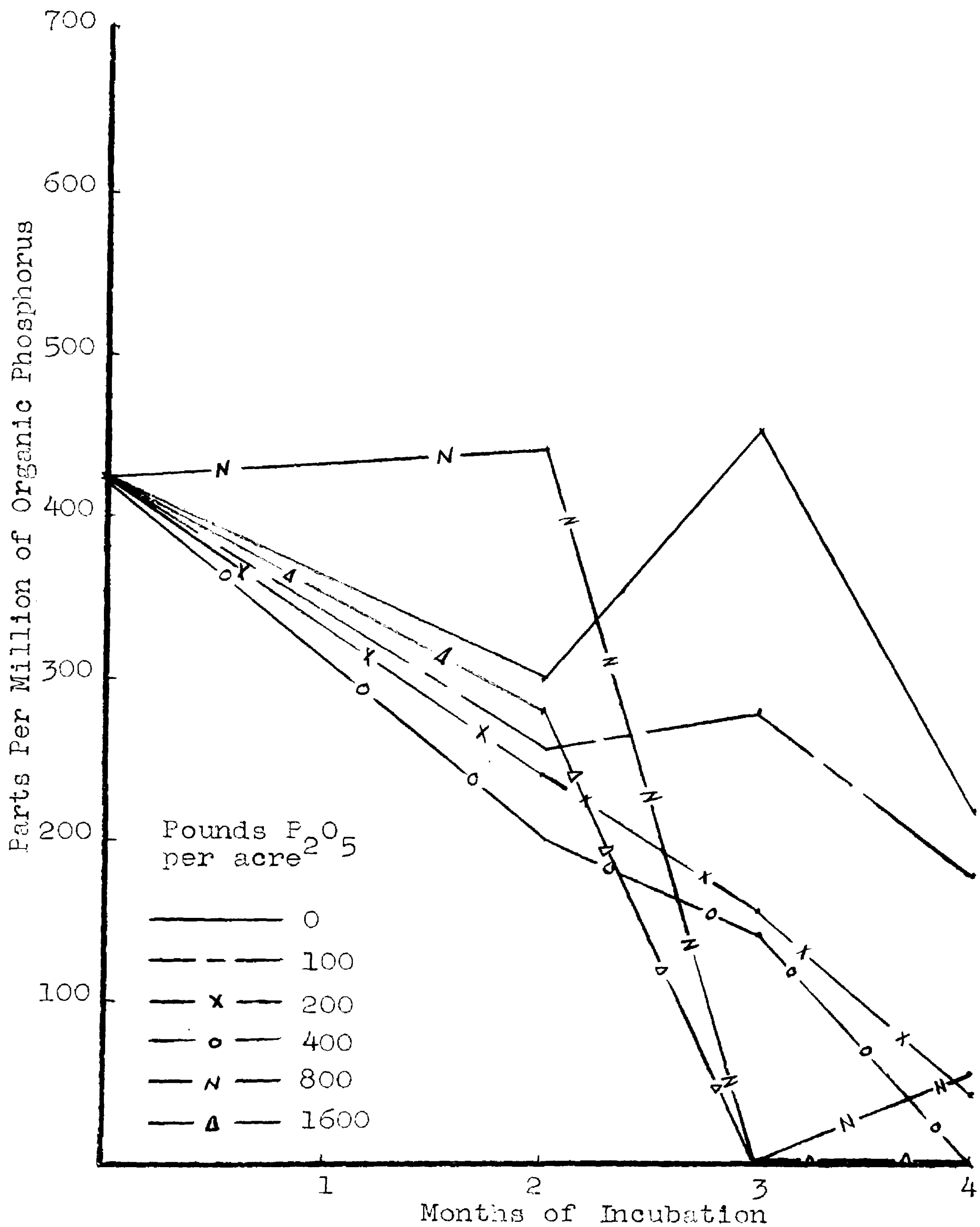

Fig. 3. The effect of $CaH_4(PO_4)_2$, applied at different rates, upon the mineralization of organic phosphorus in soil 3.

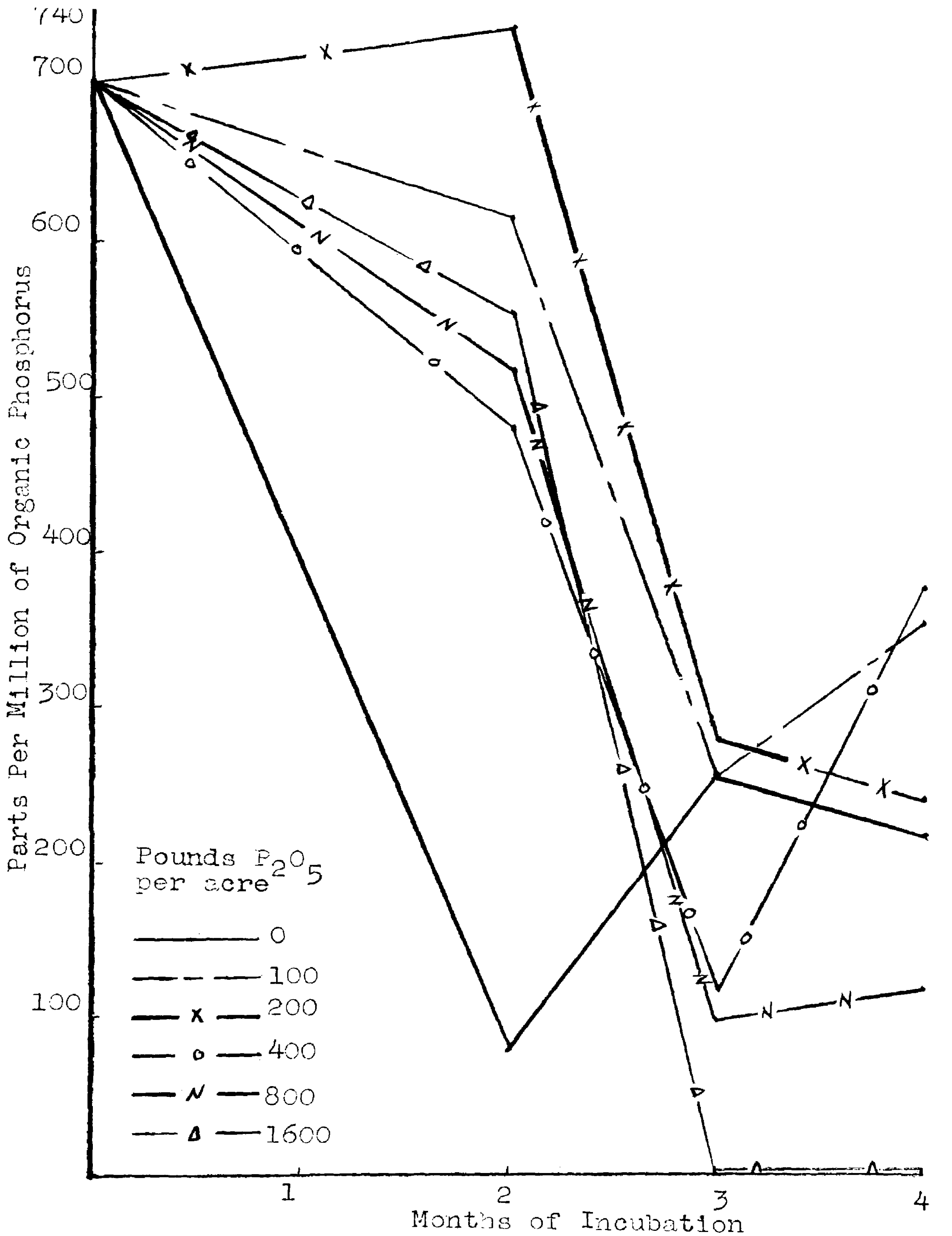

Fig. 4. The effect of $CaH_4(PO_4)_2$, applied at different rates, upon the mineralization of organic phosphorus in soil 4.

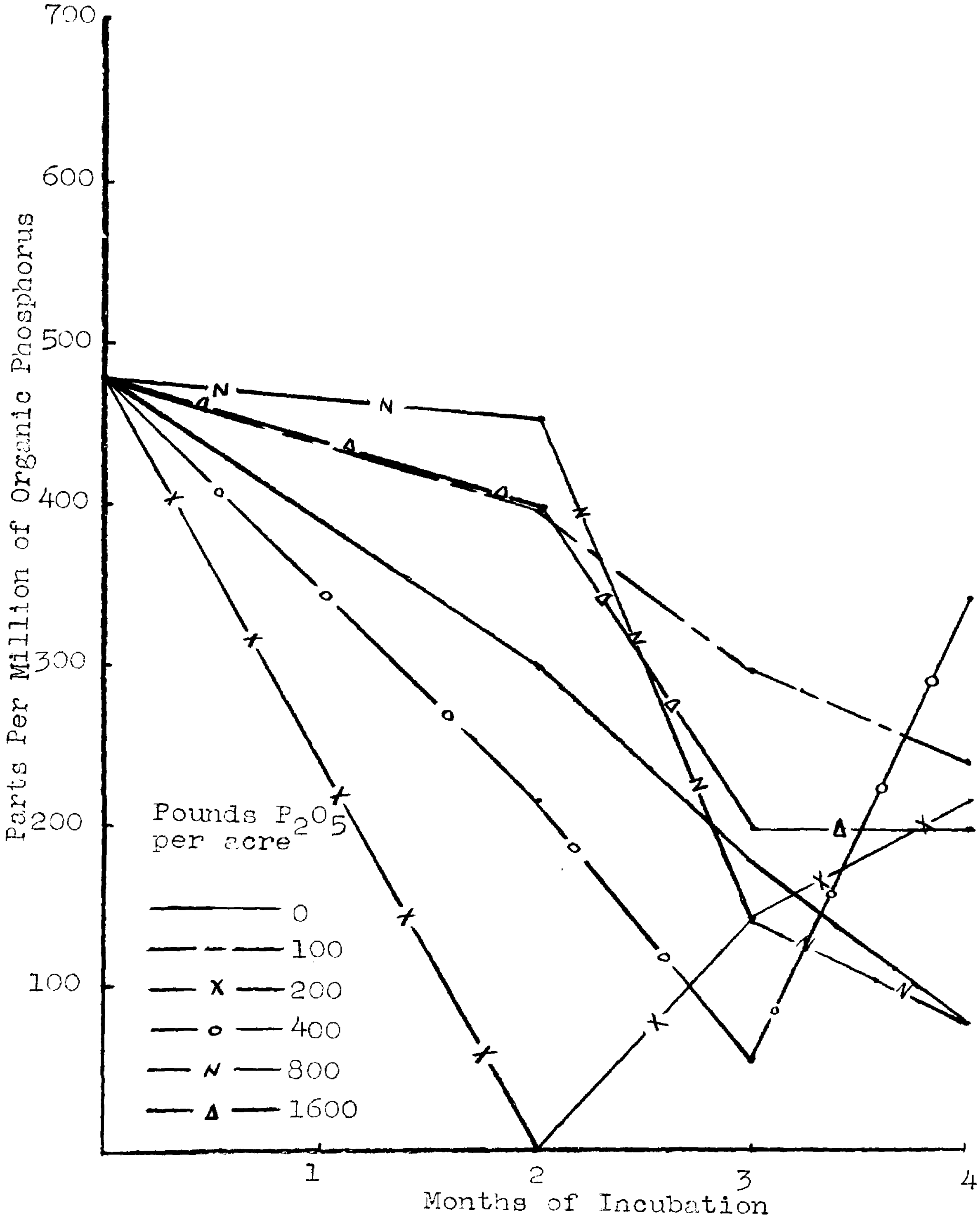

Fig. 5. The effect of $CaH_4(PO_4)_2$, applied at different rates, upon the mineralization of organic phosphorus in soil 5.

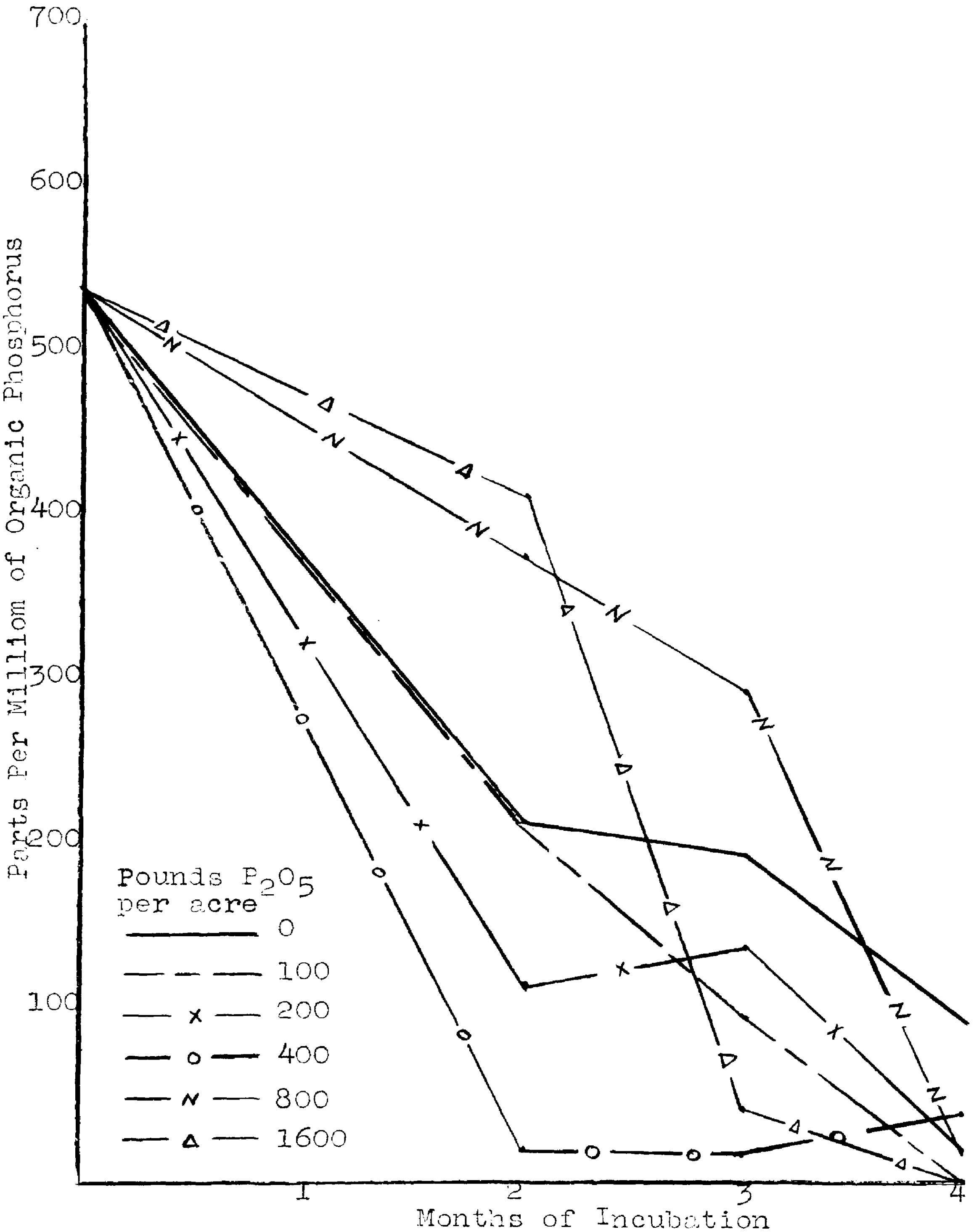

Fig. 6. The effect of $CaH_4(PO_4)_2$, applied at differnt rates, upon the mineralization of organic phosphorus in soil 6.

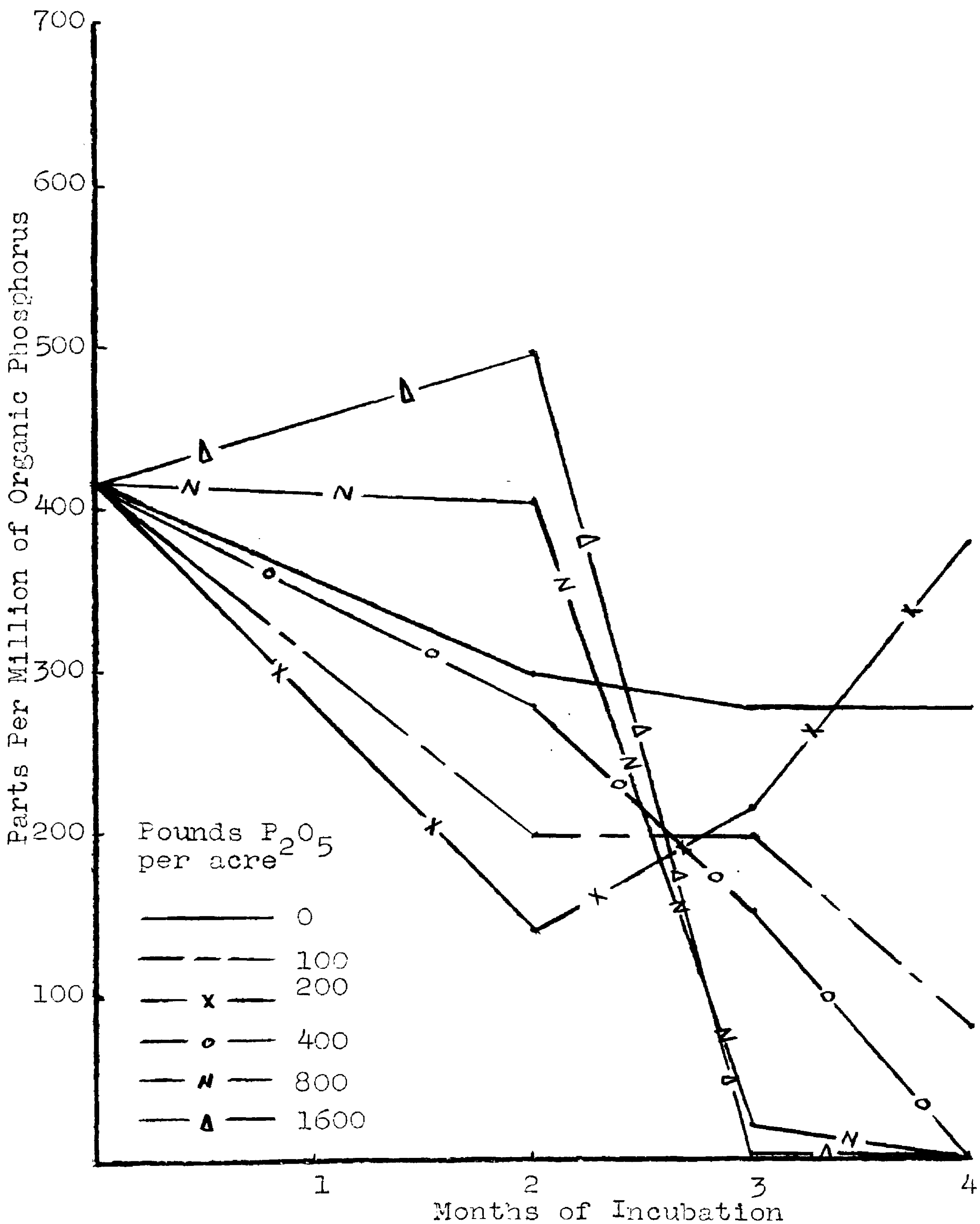

Fig. 7. The effect of $CaH_4(PO_4)_2$, applied at different rates, upon the mineralization of organic phosphorus in soil 7.

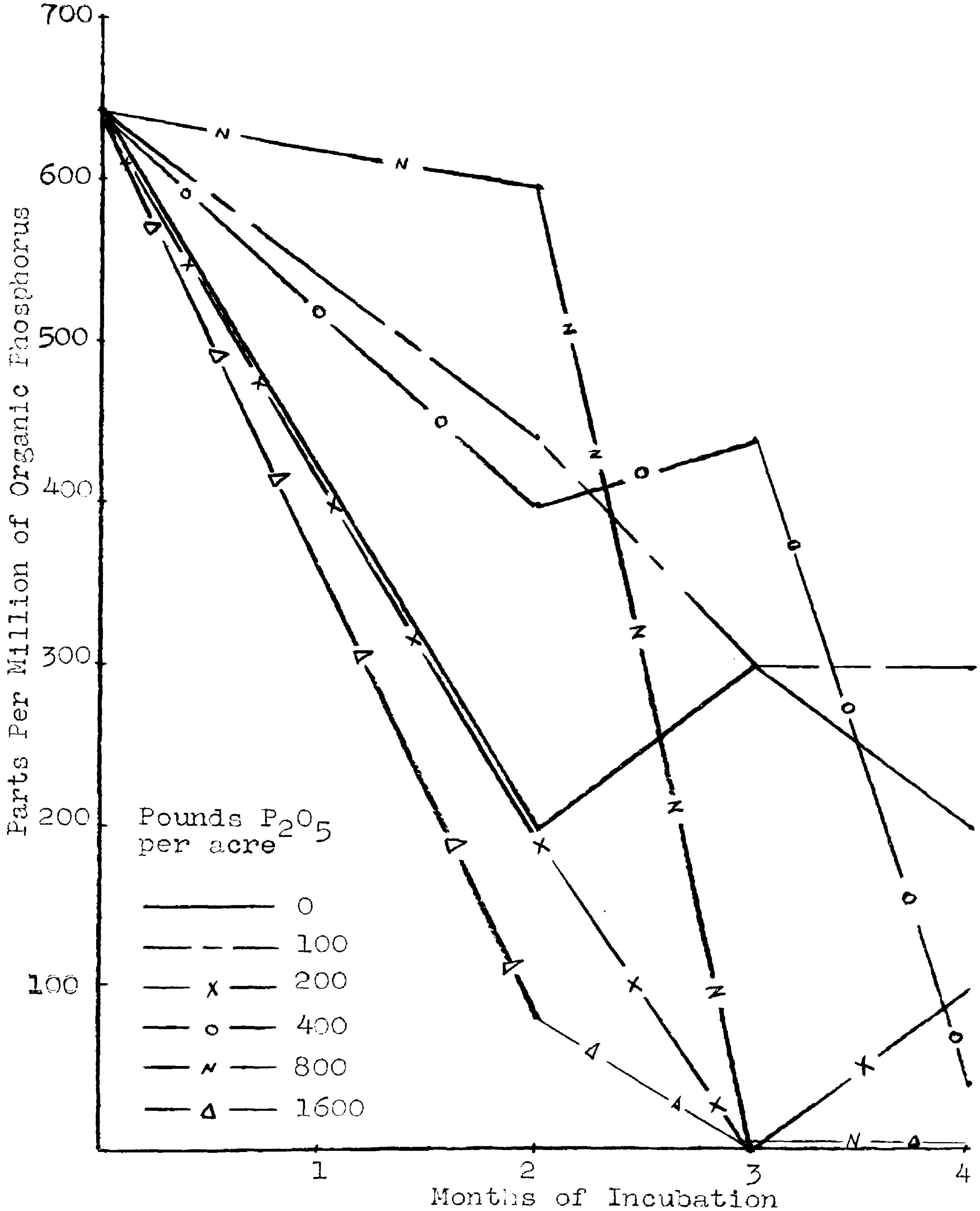

Fig. 8. The effect of $CaH_4(PO_4)_2$, applied at different rates, upon the mineralization of organic phosphorus in soil 8.