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# The Influence of Various Nitrogenous Fertilizers on the Availability of Phosphate and Potassium

By
J. Franklin Fudge

AGRICULTURAL EXPERIMENT STATION
OF THE
ALABAMA POLYTECHNIC INSTITUTE

M. J. FUNCHESS, *Director*
AUBURN

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## INTRODUCTION

THE REACTION of the soil and the concentration and nature of the various cations in the soil solution and in the exchange complex of the soil may be considered as the principal factors determining the availability of phosphate and potassium in the soil. This has been shown by the work of Burd and Martin (7, 8), Spurway (44, 45, 46), McGeorge (26), and others. Any soil treatment or amendment tending to influence either of these factors may be expected to have an influence on the availability of these two plant food elements.

Pierre (35, 36) recently published the results of an investigation on the effect of various nitrogenous fertilizers on soil reaction and on various means which may be employed in the correction of the acidity resulting from the use of certain of these fertilizers. He gives a review of a number of studies conducted by other investigators along this line. These, and similar studies, have shown that nitrogenous fertilizers may be divided on the basis of their influence on soil reaction into two main groups. Fertilizers in the first group increase soil acidity, and are known as "acid-forming" fertilizers. Ammonium sulfate may be considered as typical of this group. Other ammonium salts and urea are included in this group. Fertilizers of the second group tend to reduce soil acidity, and are therefore termed "physiologically basic" fertilizers. Sodium nitrate is typical of this group, which also includes calcium nitrate and calcium cyanamid. Since the two groups are diametrically opposed to each other in their influence on soil reaction, it is reasonable to assume that their influence on the availability of phosphate and potassium would be quite different.

Nitrogenous fertilizers also influence the concentration and nature of the cations in the soil solution and the exchange complex of the soil. Sodium nitrate and calcium nitrate, for example, may be considered as leaving residual cations of sodium and calcium in the soil. Each cation has a characteristic effect upon phosphate and potassium availability. Spurway (45) has shown that phosphate is much more soluble in a soil in which sodium is the principal exchangeable base than in one in which calcium is the principal base. Comber (12) also emphasizes the importance of the nature of the exchangeable base on the absorption of anions, including phosphate, by the soil.

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The purpose of the present investigation was to study the influence of various nitrogenous fertilizers on the availability of phosphate and potassium in a number of soils. The investigation included first, studies of soils that had received different nitrogenous fertilizers in greenhouse experiments; and second, studies of soils from long continued field experiments on sources of nitrogen. The field experiments studied included those conducted by the Agricultural Experiment Stations of New Jersey, Alabama, Rhode Island, Pennsylvania, and North Carolina. A portion of the study dealing with phosphate availability in soils from the New Jersey, Alabama, and Rhode Island Experiment Stations has already been published (16). The present paper presents the results of the entire investigation.

## METHODS

THE AVAILABILITY of phosphate and potassium was studied by determining their solubility as indicated by the concentration of displaced solutions and 1:5 extracts, using water, 0.04 N carbonic acid, and 0.2 N nitric acid as extractants. Their availability was also studied by a determination of the amounts of phosphate and potassium absorbed from the soils by the Neubauer method.

In obtaining the displaced solutions, the soils were brought to the desired moisture content, thoroughly mixed, and allowed to stand forty-eight hours. At the end of that period, the soil solutions were displaced, using the procedure described by Burd and Martin (8). All results obtained by this method are reported in parts per million of the displaced solution.

Water extracts and carbonic acid extracts were obtained by the use of collodion sacks as described by Pierre and Parker (37). Nitric acid extracts were obtained by shaking 40 gms. of soil with 200 cc. of O.2N nitric acid for 5 minutes. Shedd (42) has shown that this method gives as much or more phosphate and almost as much potassium as a method in which the soil is shaken for 5 hours. All results obtained by these methods are reported as parts per million of air-dry soil.

The availability method of Neubauer and Schneider (30) is based on the consideration that if a large number of seedlings is grown in a small amount of soil, the amount of phosphorus and potassium absorbed by the seedlings will indicate the availability of the two plant food elements. In this method, 100 rye seedlings are grown in a mixture of 100 gms. of soil and 50 gms. of sand, covered with 250 gms. of sand. All sand is previously digested in hydrochloric acid and washed with distilled water until free from chlorides. After 17 days, the seedlings are washed out of the soil and the entire plants analyzed for phosphorus and potassium. The increase in the phosphorus and potassium content of the plants grown in the mixture of soil and sand over that of plants grown in sand only is the amount of these two elements taken up from the soil. Various workers have proposed modifications of the method, but, after preliminary work, it was decided to use the regular procedure, with the single exception that instead of using rye seed, wheat seed was used. This change was made necessary because of the fact that it was impossible to secure heavy rye seed of high germination suitable for this work. While the absolute amount of phosphorus and potassium taken up by wheat seedlings may be different from that taken up by rye seedlings, differences in the availability of phosphate and potassium of the soils due to differences in sources of nitrogen will be reflected by wheat seedlings as well as by rye seedlings.

Inorganic and organic phosphates were determined in the displaced solutions and water and carbonic acid extracts by the coeruleo-molybdate method of Deniges (13) as modified for use in this type of work by Parker and Fudge (32). Pierre and Parker (38) have shown that organic phosphate, as such, is not available for the phosphorus nutrition of the plant. Its determination, however, is of value since it furnishes an indication of the amount of soluble organic phosphorus subject to mineralization by microbiological activity. Determinations of organic phosphate were therefore made in nearly all cases, but results are reported on only a few soils because there is no apparent correlation between water soluble organic phosphate and fertilizer treatment. Phosphate in nitric acid extracts and plant material was determined by the method of Fiske and Subbarow (14).

Potassium was determined colorimetrically by the method of Briggs (6), with slight modifications developed by Tidmore working in this laboratory.

Calcium was determined by the method of Clarke and Collip (11).

## GREENHOUSE STUDIES

### Experiment I

A STUDY was made of the solubility of inorganic phosphate in water extracts and of potassium in water and nitric acid extracts of five different soils used by Pierre (34) in a study of the buffer capacity of various soils and the influence of ammonium sulfate and sodium nitrate on soil reaction. They were placed in two-gallon jars and each crop was fertilized with muriate of potash and superphosphate (acid phosphate) at the rate of 100 pounds and 1,000 pounds per acre, respectively. One-third of the pots received ammonium sulfate at the rate of 1,000 pounds per acre, another third received the same amount of nitrogen in sodium nitrate, and the remainder received no nitrogen. Extracts of the soils were made after the second crop. The results of the study are given in Table 1.

**Table 1.—Reaction and concentration of inorganic phosphate and potassium in extracts of soils used in buffer study by Pierre, made after second crop.**

| Soil No. | Soil Type | Fertilizer Treatment | pH | Concentration in air-dry soil | | |
|---|---|---|---|---|---|---|
| | | | | Inorganic $PO_4$ in Water Extracts | Potassium | |
| | | | | | Water Extract | $HNO_3$ Extract |
| | | | | p.p.m. | p.p.m. | p.p.m. |
| 419 | Brown silt loam | Minerals only | 5.80 | 0.88 | 27.0 | 125.0 |
| | | Ammonium sulfate | 4.80 | 0.80 | 38.6 | 119.0 |
| | | Sodium nitrate | 6.35 | 1.96 | 17.4 | 109.0 |
| 420 | Tifton sandy loam | Minerals only | 5.65 | 0.64 | 19.7 | 46.2 |
| | | Ammonium sulfate | 4.60 | 0.44 | 21.2 | 21.3 |
| | | Sodium nitrate | 6.15 | 0.92 | 16.2 | 29.0 |
| 421 | Norfolk fine sandy loam | Minerals only | 5.20 | 0.65 | 45.2 | 85.5 |
| | | Ammonium sulfate | 4.55 | 0.52 | 45.6 | 54.6 |
| | | Sodium nitrate | 5.45 | 1.00 | 24.7 | 63.5 |
| 504 | Cecil sandy loam | Minerals only | 5.80 | 0.30 | 14.6 | 46.5 |
| | | Ammonium sulfate | 5.00 | 0.15 | 24.0 | 32.8 |
| | | Sodium nitrate | 6.10 | 1.68 | 12.6 | 39.4 |
| 557 | Lintonia silt loam | Minerals only | 6.20 | 2.12 | 14.3 | 71.0 |
| | | Ammonium sulfate | 5.00 | 1.84 | 15.6 | 52.5 |
| | | Sodium nitrate | 6.40 | 2.28 | 7.2 | 66.5 |

## Phosphate Availability

THE RESULTS show that in general the use of sodium nitrate increased the solubility of phosphate, while the use of ammonium sulfate reduced phosphate solubility. These changes in phosphate solubility apparently were correlated with the influence of the fertilizer on soil reaction. Thus, in the extract of the Cecil sandy loam, the phosphate concentration decreased from 0.30 p.p.m. in the soil receiving minerals to 0.15 p.p.m. in the soil receiving ammonium sulfate, while it increased to 1.68 p.p.m. in the soil receiving sodium nitrate. The corresponding reactions were pH 5.80, pH 5.00, and pH 6.10. On the five soils studied, the use of ammonium sulfate increased acidity in all cases and resulted in reductions of phosphate availability of 9, 31, 20, 50, and 13 per cent. Sodium nitrate, on the other hand, always caused a slight reduction in acidity, and increased phosphate solubility 121, 44, 54, 460, and 8 per cent. The differences obtained in the various soils can probably be explained by the differences in the nature of the soil phosphates and in the amount and nature of their exchangeable bases.

It is evident from the above that the influence of nitrogenous fertilizers on phosphate availability cannot be fully explained by their influence on soil reaction. As will be shown later, a large portion of the increased solubility resulting from the use of sodium nitrate is probably due to the influence of the residual sodium in the soil. It should be remembered that in the present experiment there was no opportunity for the sodium to leach from the soil. The influence of residual sodium on phosphate solubility was, therefore, probably much more marked in this experiment than would be expected under field conditions where a large part of the sodium is readily removed by leaching. The general effect of the two nitrogenous fertilizers on the availability of phosphate has been a decrease due to acidity developed following nitrification of ammonium sulfate, and an increase due to a reduction in acidity and introduction of considerable quantities of sodium following the use of sodium nitrate.

## Potassium Availability

IN THREE cases out of the five, water extracts of the soils receiving ammonium sulfate contained more potassium than those from the check, and in the other two, about the same amount. The increases were due to the increased acidity resulting from the nitrification of the ammonium sulfate. Sodium nitrate in every case caused significant decreases in the amount of potassium in water extracts. Apparently the decrease in acidity and the residual sodium repressed the solubility of potassium. The nitric acid extracts did not show any significant difference in their potassium content other than that all soils which received nitrogenous fertilizers contained less soluble potassium than did the checks which received minerals only. This was undoubtedly due to the greater plant growth and consequent potassium removal on the former soils. Differences in plant growth and potassium removal probably also explain the fact that nitric acid-soluble potassium was slightly higher in pots receiving sodium nitrate than in those receiving ammonium sulfate.

### Experiment II

IN THE preceding study, only two nitrogenous fertilizers were used. Another experiment was conducted on a Norfolk sandy loam and on a Cecil clay loam in which a larger number was used. The fertilizer treatment was essentially the same as in the preceding experiment. Pierre (35) has already reported the results of the study on soil reaction as influenced by the several nitrogenous fertilizers. The study of the solubility of phosphate and potassium was made on extracts of soil samples taken after the second crop. The results of this experiment are given in Table 2.

**Table 2.—Reaction and concentration of inorganic phosphate and potassium in water extracts of a Norfolk sandy loam and a Cecil clay loam**

| Source of Nitrogen | Norfolk Sandy loam | | | Cecil clay loam | | |
|---|---|---|---|---|---|---|
| | pH | $PO_4$ | K | pH | $PO_4$ | K |
| | | p.p.m. | p.p.m. | | p.p.m. | p.p.m. |
| None | 5.50 | 0.30 | 21.6 | 6.03 | 0.14 | 5.3 |
| Minerals only | 5.20 | 3.40 | 28.6 | 5.78 | 0.72 | 25.8 |
| Sodium nitrate | 6.25 | 6.00 | 6.7 | 6.60 | 1.48 | 6.1 |
| Ammonium sulfate | 4.43 | 0.50 | 20.9 | 4.98 | 0.16 | 20.6 |
| Urea | 5.03 | 2.16 | 8.2 | 5.60 | 0.88 | 9.4 |
| Ammonium nitrate | 4.95 | 2.80 | 6.5 | 5.55 | 0.46 | 7.5 |
| Leunasalpeter | 4.50 | 1.60 | 31.8 | 5.18 | Trace | 17.5 |
| Calcium cyanamid | 6.15 | 2.16 | 5.4 | 6.30 | 0.70 | 6.4 |
| Calcium nitrate | 5.75 | 2.56 | 6.8 | 6.23 | 0.25 | 7.7 |

### Phosphate Availability

THE CHANGES in solubility of phosphate due to the nitrogenous fertilizers are again correlated very closely with the changes in reaction of the soils and with the nature of the residual bases derived from the fertilizer. Ammonium sulfate caused the greatest decrease in phosphate solubility and the greatest increase in acidity. The soils receiving this fertilizer together with a relatively large application of superphosphate (acid phosphate) contained but little more water-soluble phosphate than did the soils which had received no phosphatic fertilization, and but 15 per cent as much as the check, receiving minerals only, in the case of the Norfolk sandy loam, and 22 per cent as much in the case of the Cecil clay loam. Leunasalpeter caused such a marked reduction in phosphate solubility that the soil receiving this source of nitrogen contained less than half as much water-soluble phosphate as the check, in the case of the Norfolk sandy loam, and only a trace of phosphate in the case of the Cecil clay loam. This source of nitrogen was second only to ammonium sulfate in its power to increase acidity. There is very little difference in the effects of calcium nitrate, calcium cyanamid, ammonium nitrate, and urea upon phosphate availability, although the first two salts caused a decrease in acidity while the last two caused an increase. The decrease in phosphate solubility following the use of ammonium nitrate and urea may be explained on the basis of their influence on acidity. The decrease following the use of the calcium salts apparently is due to the fact that calcium tends to repress phosphate solubility. It is well known that an increase in the calcium content of the soil solution has a depressive effect upon the solubility of rock phosphate or tricalcium phosphate, when the addition of the calcium-containing materials do not cause such a great decrease in acidity that reaction rather than calcium is the determining factor in phosphate availability. The calcium had no opportunity to leach from the soils used in this study, and hence by the law of mass action, the solubility of the tricalcium phosphate was lowered. Consequently, the concentration of phosphate in the water extracts was decreased, even though the calcium-containing nitrogenous fertilizers caused very significant decreases in acidity.

The use of sodium nitrate resulted in a very large increase in water-soluble phosphate in both soils, due to the decrease in acidity and the incorporation of large amounts of sodium in the soil. In the Norfolk sand, the increase over the check due to the use of sodium nitrate was 76 per cent, and in the Cecil clay loam, it was 106 per cent. No other source of nitrogen resulted in an increase in water-soluble phosphate content exceeding that of the check, which received minerals only. This was in part due to the fact that the check in both series produced practically no growth, while all cultures receiving the nitrogen produced good yields the first crop, and the cultures of Norfolk sandy loam receiving ammonium sulfate were the only ones which gave an extremely poor yield the second crop. This explanation could not be advanced for the cultures receiving sodium nitrate, however, since these cultures produced heavy yields on both soils. There is evidently a very great solubility effect due to the use of sodium nitrate. As noted in the consideration of the results of the first greenhouse study, this effect is much more pronounced under greenhouse conditions than it would be in the field, where the sodium would be leached out and the applications of fertilizer would not be so heavy. It is apparent from this work, however, that sodium nitrate causes the greatest increase in water-soluble phosphate with a corresponding decrease in acidity, ammonium sulfate causes the greatest decrease in phosphate solubility accompanied by the greatest increase in acidity and other sources of nitrogen are intermediate in effect on both phosphate solubility and acidity.

### Potassium Availability

SOILS receiving minerals only, ammoninum sulfate, and Leunasalpeter contained much more water-soluble potassium than soils receiving any other source of nitrogen. In the case of the check, the high concentration was due to the heavy fertilization without subsequent plant removal, while in the extracts of the soils receiving ammonium sulfate and Leunasalpeter, it was undoubtedly due to the high acidity developed following their use. The other nitrogenous fertilizers did not differ greatly among themselves in their effect on potassium solubility. All of them gave very low concentrations of potassium in the extracts. The low results obtained from the soil cultures receiving sodium nitrate, calcium nitrate, and calcium cyanamid may be explained as due to the repression of potassium solubility by residual sodium and calcium. This does not explain, however, the low results obtained with urea and ammonium nitrate. These two fertilizers do not leave a residual base, and as shown by Pierre (35), they form one-half as much acid as ammonium sulfate.

## STUDIES OF PLATS FROM SOURCES OF NITROGEN EXPERIMENTS

THE GREENHOUSE studies indicated an increased availability of phosphate due to the use of physiologically basic nitrogenous fertilizers and a decrease due to the use of acid-forming fertilizers. The correlation between potassium availability and source of nitrogen was not so definite, but certain tendencies were evident. The question arose as to whether these results would be evident in soils under field conditions. This question could be answered by a study of soils from field experiments. The purpose of this part of the investigation was to study the availability of phosphate and potassium in plats of the long continued sources of nitrogen experiments of the New Jersey, Alabama, Rhode Island, Pennsylvania, and North Carolina Experiment Stations.

Attention should be called to the fact that in these experiments crop yield differences on the various plats have been very great for many years. In most cases, where lime has not been added to correct the acidity, ammonium sulfate has caused a marked decrease in yield, as compared with the check plat while physiologically basic fertilizers have caused large increases. For example, on the New Jersey unlimed plats (24) plat 11A, receiving ammonium sulfate, produced 23.6 per cent less dry matter than the check, plat 4A. At the same time, plat 9A, receiving sodium nitrate, produced 81.4 per cent, and plat 10A, receiving calcium nitrate, produced 55.6 per cent more than plat 4A. Consequently, there has been a much more efficient use of phosphate and potassium fertilizers and a heavier drain on the available supply of these two elements in those plats which received physiologically basic fertilizers.

## NEW JERSEY EXPERIMENT STATION PLATS

### History of Plats

THE SOURCES of nitrogen plats at the New Jersey Experiment Station were started in 1908. The details of the fertilizer treatment are given in various publications from that Station (22, 23, 24). Until 1922, the fertilizer treatment was at the rate of 840 pounds of superphosphate (acid phosphate), 320 pounds of muriate of potash, and 320 pounds of sodium nitrate or its nitrogen equivalent per acre. In 1922 and succeeding years, mineral fertilizers were reduced to 320 pounds of superphosphate (acid phosphate) and 160 pounds of muriate of potash per acre. Dried blood, applied on plat 13, was discontinued in 1922, and nothing substituted for it. Half the plats received lime and the other half did not. Samples of the plats, both limed and unlimed sections, were taken in the spring of 1926 and sent to Auburn for this work.

### Phosphate Availability

**Displaced solutions and 1:5 extracts:** Easily soluble phosphates were determined in the displaced solutions and in 1:5 extracts, using distilled water, 0.04 N carbonic acid, and 0.2 N nitric acid as extractants. Table 3 gives the reaction of the soil and the amounts of inorganic and organic phosphate in the soil solution and various extracts.

On the unlimed plats, the acidity of plat 9A, receiving sodium nitrate, decreased from pH 4.85 to pH 5.20, and this plat contained more soluble inorganic phosphate than any other unlimed plat. At the same time, the acidity of plat 11A, which received ammonium sulfate, increased from pH 4.85 to pH 4.25, and there was a corresponding decrease in phosphate availability. Thus, the water extract of plat 9A contained over eight times as much inorganic phosphate as the extract of plat 11A, and about three times as much as the check, plat 4A. All other plats receiving physiologically basic nitrogenous fertilizers and dried blood gave phosphate solubilities intermediate between these two sources. Ammonium sulfate is the only source of nitrogen which noticeably increased acidity, and is the only one which did not increase phosphate availability, when compared with the check plat.

The influence of the cation on phosphate availability is also very evident from a study of plats 9A, 10A, and 12A, receiving sodium nitrate, calcium nitrate, and calcium cyanamid, respectively. There is very little difference in the acidity of these plats, their reactions being pH 5.20, pH 5.15, and pH 5.35. Any difference in phosphate availability cannot, therefore, be ascribed to differences in acidity. The concentrations of inorganic phosphate in the water extracts of the three soils, however, are 3.30 p.p.m., 2.65 p.p.m., and 2.63 p.p.m., indicating a greater availability of phosphate in plat 9A than in the other two plats. The explanation of the difference lies in the fact that plat 9A

**Table 3.—Solubility of inorganic and organic phosphates in soil from the New Jersey Experiment Station as influenced by various nitrogenous fertilizers.***

| Plat No. | Source of nitrogen | pH | Inorganic $PO_4$ Displaced solution | Inorganic $PO_4$ Extracts $H_2O$ | Inorganic $PO_4$ Extracts $H_2CO_3$ | Inorganic $PO_4$ Extracts $HNO_3$ | Organic $PO_4$ Displaced solution | Organic $PO_4$ Water extract |
|---|---|---|---|---|---|---|---|---|
| | | | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. |
| | **Unlimed Sections** | | | | | | | |
| 4A | Minerals only | 4.85 | 0.14 | 1.12 | 0.8 | 236 | 0.48 | 0.33 |
| 7A | No fertilizer | 4.60 | 0.10 | 0.24 | 0.9 | 37 | 0.03 | 0.29 |
| 8A | ½ Sodium nitrate | 5.25 | 0.16 | 2.35 | 2.9 | 213 | 0.15 | 0.55 |
| 9A | Sodium nitrate | 5.20 | 0.23 | 3.30 | 4.8 | 325 | 0.17 | 0.65 |
| 10A | Calcium nitrate | 5.15 | 0.17 | 2.65 | 1.9 | 180 | 0.02 | 0.15 |
| 11A | Ammonium sulfate | 4.25 | 0.07 | 0.40 | 0.8 | 281 | 0.29 | 0.27 |
| 12A | Calcium cyanamid | 5.35 | 0.14 | 2.63 | 2.6 | 258 | 0.07 | 0.27 |
| 13A | Dried blood | 4.75 | 0.25 | 0.72 | 2.2 | 265 | 0.06 | 1.13 |
| | **Limed Sections** | | | | | | | |
| 4B | Minerals only | 6.45 | 0.40 | 10.00 | 12.8 | 320 | 0.14 | 0.35 |
| 7B | No fertilizer | 6.35 | 1.00 | 8.45 | 13.5 | 387 | 0.44 | 0.25 |
| 8B | ½ Sodium nitrate | 6.35 | 0.60 | 7.90 | 10.4 | 336 | 0.24 | 0.20 |
| 9B | Sodium nitrate | 6.55 | 0.62 | 10.40 | 16.1 | 336 | 0.26 | 0.25 |
| 10B | Calcium nitrate | 6.50 | 0.56 | 7.40 | 13.9 | 376 | 0.24 | 0.10 |
| 11B | Ammonium sulfate | 6.20 | 2.10 | 19.15 | 23.8 | 462 | 0.20 | 0.85 |
| 12B | Calcium cyanamid | 6.35 | 0.56 | 3.85 | 9.8 | 284 | 0.44 | 0.15 |
| 13B | Dried blood | 6.05 | 1.08 | 1.12 | 1.6 | 67 | 0.34 | 0.45 |

* In this and succeeding tables concentration of displaced solution is given in p.p.m. of solution and the concentration of all extracts, in p.p.m. of air-dry soil.

receives sodium while the other two plats receive calcium as the base carried in the nitrogenous fertilizer. The sodium compounds of phosphorus are much more soluble than are the calcium compounds, and this difference is reflected in the results of the various methods of studying phosphate availability. It should be noticed that the various solubility methods of studying availability give, in general, similar results.

Accompanying the greatly reduced acidity on the limed sections, there was an increased phosphate availability on all plats except plat 13B. The greatest change was on plat 11B, receiving ammonium sulfate. The liming of this plat reduced acidity from pH 4.25 to pH 6.20, and increased the water-soluble inorganic phosphate from 0.4 p.p.m. to 19.2 p.p.m. With the exception of plat 11B, plat 9B, receiving sodium nitrate, gave the highest phosphate solubility. Liming so greatly increased the availability that the addition of a basic nitrogenous fertilizer had no appreciable effect.

On the unlimed sections, the plat receiving minerals only contained the greatest amount of organic phosphate in the displaced solution, followed by that of the plat receiving ammonium sulfate. The water extract of the plat receiving dried blood contained much more organic phosphate than that of any other plat; this plat was followed by the plat receiving sodium nitrate. With the exception of the water extract of plat 11B, the limed ammonium sulfate plat, there were no significant differences between the various plats of the limed sections.

**Leaching method:** Studies on the concentration of a plant food element in displaced solutions and extracts do not indicate the ability of a soil to maintain a given concentration over a considerable period during which the element is being absorbed by the plant. Parker (31) has shown that, in the phosphorus nutrition of the plant, the concentration of phosphate beyond a very low figure is by no means as important as is the maintenance of that concentration. In order to secure a better indication of the ability of the soil to maintain a given concentration of phosphate, the following experiment was conducted:

Ten grams of soil were placed in a 25 cc. Gooch crucible and leached with 300 cc. of water. The water was added in 10 cc. portions, and each portion was drawn through by suction before the next portion was added. The leachate was collected in six successive 50 cc. portions, and analyzed for inorganic phosphate. The data secured in this work are given in Table 4.

The phosphate content of the first 50 cc. portion was quite high, but diminished in the second and third portions. The fourth, fifth, and sixth portions were practically the same, and the concentration of the fourth portion may be taken to represent the equilibrium point of each soil under the conditions of the experiment.

The sodium nitrate plat gave the highest initial concentrations of phosphate on the unlimed sections, followed by plats receiving

**Table 4.—Availability of inorganic phosphate and potassium in soils from the New Jersey Experiment Station as indicated by continued leaching.**

| Plat No. | Source of Nitrogen | Inorganic Phosphate | | | | | | Potassium | |
|---|---|---|---|---|---|---|---|---|---|
| | | First 50 cc. | | Fourth 50 cc. | | Total $PO_4$ | | Total | |
| | | Unlimed | Limed | Unlimed | Limed | Unlimed | Limed | Unlimed | Limed |
| | | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. |
| 4 | Minerals only | 4.9 | 18.4 | 2.4 | 8.3 | 20.0 | 70.7 | 38.6 | 37.6 |
| 7 | No fertilizer | 1.0 | 22.9 | 0.6 | 11.4 | 3.9 | 89.4 | 23.4 | 39.2 |
| 8 | ½ Sodium nitrate | 12.0 | 28.2 | 7.2 | 10.3 | 54.3 | 95.3 | 33.2 | 41.5 |
| 9 | Sodium nitrate | 15.6 | 33.8 | 12.9 | 18.6 | 79.6 | 130.8 | 44.6 | 66.5 |
| 10 | Calcium nitrate | 11.5 | 20.0 | 6.3 | 12.3 | 46.5 | 83.6 | 36.4 | 40.0 |
| 11 | Ammonium sulfate | 0.9 | 55.0 | 1.4 | 20.3 | 7.3 | 168.8 | 22.8 | 49.0 |
| 12 | Calcium cyanamid | 12.1 | 13.9 | 6.4 | 8.6 | 46.2 | 58.4 | 56.0 | 74.0 |
| 13 | Dried blood | 11.1 | 2.5 | 5.7 | 1.1 | 45.9 | 9.3 | 40.3 | 60.2 |

calcium cyanamid, one-half sodium nitrate, calcium nitrate and dried blood, the latter four treatments being practically equal in their effect on phosphate solubility. Plats receiving minerals alone, no fertilizer, and ammonium sulfate gave very low concentrations. Liming greatly increased the solubility of phosphate. The limed ammonium sulfate plat gave the highest concentration, followed by the sodium nitrate plat. With the exception of the calcium cyanamid and dried blood plats, which were comparatively quite low, all other plats gave practically the same concentration. The relative increase due to liming was dependent upon the source of nitrogen. On the ammonium sulfate plat, liming gave an increase of over 6,000 per cent, on the sodium nitrate plat an increase of 116 per cent, on the calcium cyanamid plat an increase of 15 per cent, and on the dried blood plat a decrease of 78 per cent.

An interesting comparison of this method and the regular 1:5 water extract is given by comparing the phosphate concentrations of the first 50 cc. portion with those of the 1:5 water extracts given in Table 1. For example, plat 9A by the latter method gave only 3.3 p.p.m. $PO_4$, while in the leaching method it gave 15.6 p.p.m. The ratio of soil to water is the same in both methods, the difference probably being due to the removal by the leaching method of the soluble cations which depress the solubility of the phosphates.

The relative order of the phosphate solubility of the different plats is essentially the same in the fourth 50 cc. portion as in the first 50 cc., although the differences in phosphate concentration are much smaller. The effect of liming is still evident, but the difference between limed and unlimed sections is smaller, indicating that a large amount, but by no means all, of the additional available phosphate in the limed sections is tied up in easily soluble compounds.

The figures given under the columns headed "Total $PO_4$" represent the total amount of phosphate removed by the 300 cc. of water. As is to be expected, the same order of phosphate differences was maintained. The sodium nitrate plat contained considerably more soluble phosphate than any other plat of the unlimed sections, and was second only to the ammonium sulfate plat of the limed sections. Sodium nitrate quadrupled, and other sources more than doubled the amount of soluble phosphates, when compared with the check. The increase in soluble phosphates due to the nitrogenous fertilizer was not so marked on the limed plats, but was significant in all cases except with calcium cyanamid and dried blood, which caused decreases.

The experiment has shown again very clearly that sodium nitrate gave the greatest amount of soluble phosphate, and ammonium sulfate the least when lime was not used to correct acidity and supply bases. When lime was used, the ammonium sulfate plat contained the largest amount of soluble phosphate, followed by the sodium nitrate plat.

**Absorption method:** The work on continued leaching indicated large differences in the solubility of phosphate in the different soils. The question arose as to whether the amount of phosphate necessary to satisfy the phosphate absorptive capacity of the soils might not also vary widely. In order to study this question, ten grams of soil were shaken with 500 cc. of a solution of monopotassium phosphate containing 100 p.p.m. of $PO_4$ until equilibrium had been established between the soil and the solution. The concentration of phosphate in the solution was then determined and the amount of phosphate absorbed by the soil calculated. On the unlimed sections, the plats receiving sodium nitrate gave the least absorption. The absorption was slightly greater in plats receiving minerals only and minerals and dried blood, while the plat which received ammonium sulfate absorbed 50 per cent more than the plat receiving nitrate of soda. Liming materially decreased absorption, and there were no very significant differences on the plats of this section.

**Neubauer seedling method:** The preceding results have shown significant differences in solubility of phosphates due to various nitrogenous fertilizers. The question arose as to whether these differences would be reflected as strongly in the utilization of the phosphate by plants grown in the soils. The method developed by Neubauer and Schneider (30) was used in the study of this question. The results are given in Table 5.

**Table 5.—Results of Neubauer tests of soils from the New Jersey Experiment Station**

| Plat No. | Source of Nitrogen | Milligrams absorbed from soil | | | |
|---|---|---|---|---|---|
| | | Phosphate | | Potassium | |
| | | Unlimed | Limed | Unlimed | Limed |
| 4 | Minerals only | 5.3 | 10.8 | 12.4 | 12.1 |
| 7 | No fertilizer | 3.8 | 10.5 | 7.0 | 8.8 |
| 8 | ½ Sodium nitrate | 6.6 | 16.6 | 12.4 | 14.2 |
| 9 | Sodium nitrate | 11.1 | 16.4 | 14.1 | 18.0 |
| 10 | Calcium nitrate | 7.3 | 13.3 | 9.8 | 16.0 |
| 11 | Ammonium sulfate | 2.9 | 22.1 | 11.4 | 11.8 |
| 12 | Calcium cyanamid | 8.9 | 12.0 | 12.8 | 7.7 |
| 13 | Dried blood | 10.4 | 5.2 | 4.3 | 3.7 |

In the plats of the unlimed section, the maximum absorption of phosphate by the seedlings, 11.1 mgm., was from plat 9A, receiving sodium nitrate, and the least absorption, 2.9 mgm., was from plat 11A, receiving ammonium sulfate. Plats receiving dried blood, calcium cyanamid, calcium nitrate and one-half the regular amount of sodium nitrate, supplying 10.4 mgm., 8.9 mgm., 7.3 mgm., and 6.6 mgm., of phosphate, respectively, contained more phosphate available to the seedlings than the check plat, which gave 5.3 mgm. Liming increased the phosphate absorption of all plats except 13B, receiving dried blood. Plat 11B gave the maximum amount, 22.1 mgm., followed by plats 8B and 9B, with 16.6 mgm. and 16.4 mgm., respectively. Plats 10B and

**Table 6.—Relative solubility of inorganic pnosphate in soil from the New Jersey Experiment Station, as influenced by various nitrogenous fertilizers.**

| Plat No. | Source of nitrogen | pH | Relative Solubility of Phosphate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Displaced solution | Extracts | | | Neubauer | Leaching | Average |
| | | | | $H_2O$ | $H_2CO_3$ | $HNO_3$ | | | |
| | | | Unlimed Sections | | | | | | |
| 4A | Minerals only | 4.85 | 61 | 37 | 19 | 73 | 48 | 25 | 44 |
| 7A | No fertilizer | 4.60 | 43 | 8 | 17 | 11 | 34 | 5 | 20 |
| 8A | ½ Sodium nitrate | 5.25 | 69 | 78 | 60 | 65 | 60 | 68 | 67 |
| 9A | Sodium nitrate | 5.20 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 10A | Calcium nitrate | 5.15 | 74 | 87 | 40 | 56 | 67 | 59 | 64 |
| 11A | Ammonium sulfate | 4.25 | 34 | 12 | 17 | 86 | 26 | 9 | 31 |
| 12A | Calcium cyanamid | 5.35 | 61 | 87 | 54 | 78 | 80 | 59 | 70 |
| 13A | Dried blood | 4.75 | 108 | 24 | 46 | 82 | 94 | 58 | 69 |
| | | | Limed Sections | | | | | | |
| 4B | Minerals only | 6.45 | 435 | 256 | 281 | 99 | 95 | 89 | 209 |
| 7B | No fertilizer | 6.35 | 174 | 303 | 266 | 116 | 97 | 112 | 178 |
| 8B | ½ Sodium nitrate | 6.35 | 261 | 240 | 216 | 104 | 150 | 120 | 182 |
| 9B | Sodium nitrate | 6.55 | 270 | 316 | 335 | 104 | 148 | 165 | 223 |
| 10B | Calcium nitrate | 6.50 | 244 | 224 | 290 | 116 | 120 | 105 | 186 |
| 11B | Ammonium sulfate | 6.20 | 915 | 580 | 495 | 142 | 199 | 206 | 323 |
| 12B | Calcium cyanamid | 6.35 | 244 | 117 | 204 | 87 | 108 | 74 | 139 |
| 13B | Dried blood | 6.05 | 470* | 34 | 33 | 20 | 45 | 12 | 24 |

* Not included in average.

12B, receiving calcium nitrate and calcium cyanamid, gave 13.3 mgm. and 12.0 mgm., amounts considerably larger than plat 4, the check, with 10.8 mgm. The relative order of the various nitrogenous fertilizers, as affecting phosphate solubility, secured by this method agrees very closely with that secured by the preceding methods.

## Comparison of Methods

A COMPARISON of the data on relative phosphate availability of the various plats as determined by the different methods is given in Table 6. Using plat 9A as the basis of comparison and giving to this plat the value of 100 in each of the several methods, plat 11A, receiving ammonium sulfate, has shown relative phosphate availabilities of 34, 12, 17, 86, 26, and 9, or an average of 31. Plat 10A, receiving calcium nitrate gave corresponding figures of 74, 87, 40, 56, 67, and 59, averaging 64. The check plat, plat 4A, gave values of 61, 37, 19, 73, 48, and 25, averaging 44. The eight unlimed plats may be divided into three groups, based on the relative availability of inorganic phosphate: First, plat 9A, reeciving sodium nitrate, the standard; second, plats 8A, 10A, 12A, and 13A, receiving one-half sodium nitrate, calcium nitrate, cyanamid, and dried blood, all giving about two-thirds the availability of the standard; and third plats 4A, 7A, and 11A, receiving minerals only, no fertilizer, and ammonium sulfate, respectively, giving about one-third the availability of the standard.

All methods showed a marked increase in phosphate availability due to liming. A much greater increase in phosphate availability was indicated, however, by the displaced solutions and water and carbonic acid extracts than by continued leaching and the Neubauer method. The difference in these two groups of methods indicates that a considerable portion of the increased amount of available phosphate was combined in comparatively very soluble compounds. The increases due to liming were so great that differences in phosphate availability due to nitrogenous fertilization were of very minor importance.

## Potassium Availability

DETERMINATIONS of potassium were made on the same solutions which were used for the phosphate determinations. Table 7 gives the actual amounts of potassium determined in the displaced solutions and the various extracts, while Table 8 gives the relative availability by these methods, using the unlimed sodium nitrate plat as the standard. Results of the potassium study of the continued leaching experiment and the Neubauer tests are included with those of the phosphate study given in Tables 4 and 5.

In the case of potassium, there is not the clear correlation between reaction and availability which was evident in the case of phosphate, nor do the various methods agree so well as to

**Table 7.—Solubility of potassium and calcium in soil from the New Jersey Experiment Station, as influenced by various nitrogenous fertilizers.**

| Plat No. | Source of nitrogen | pH | Potassium | | | | Calcium | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Displaced solution | Extracts | | | Displaced solution | Extracts | | |
| | | | | $H_2O$ | $H_2CO_3$ | $HNO_3$ | | $H_2O$ | $H_2CO_3$ | $HNO_3$ |
| | | | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. |
| | | | | Unlimed Sections | | | | | | |
| 4A | Minerals only | 4.85 | 114.3 | 57.5 | 68 | 280 | 171 | 34.9 | 60 | 395 |
| 7A | No fertilizer | 4.60 | 67.0 | 22.6 | 28 | 135 | 86 | 19.2 | 36 | 145 |
| 8A | ½ Sodium nitrate | 5.25 | 57.4 | 31.0 | 55 | 264 | 198 | 22.8 | 54 | 370 |
| 9A | Sodium nitrate | 5.20 | 77.2 | 54.0 | 70 | 324 | 240 | 30.0 | 70 | 390 |
| 10A | Calcium nitrate | 5.15 | 33.6 | 34.2 | 53 | 258 | 206 | 27.2 | 78 | 500 |
| 11A | Ammonium sulfate | 4.25 | 117.5 | 66.0 | 106 | 278 | 184 | 24.8 | 58 | 135 |
| 12A | Calcium cyanamid | 5.35 | 41.6 | 31.6 | 49 | 224 | 194 | 25.6 | 78 | 555 |
| 13A | Dried blood | 4.75 | 31.6 | 51.4 | 68 | 314 | 187 | 30.0 | 60 | 305 |
| | | | | Limed Sections | | | | | | |
| 4B | Minerals only | 6.45 | 113.2 | 47.3 | 83 | 280 | 488 | 54.4 | 232 | 1075 |
| 7B | No fertilizer | 6.35 | 41.2 | 22.9 | 45 | 151 | 460 | 23.6 | 156 | 905 |
| 8B | ½ Sodium nitrate | 6.35 | 55.4 | 59.5 | 83 | 309 | 360 | 63.6 | 244 | 1130 |
| 9B | Sodium nitrate | 6.55 | 64.0 | 47.0 | 70 | 314 | 380 | 70.0 | 246 | 1400 |
| 10B | Calcium nitrate | 6.50 | 10.8 | 49.7 | 62 | 136 | 192 | 68.0 | 244 | 1290 |
| 11B | Ammonium sulfate | 6.20 | 39.2 | 43.8 | 61 | 308 | 152 | 58.4 | 176 | 1370 |
| 12B | Calcium cyanamid | 6.35 | 50.0 | 24.3 | 42 | 188 | 280 | 68.3 | 260 | 1550 |
| 13B | Dried blood | 6.05 | 41.2 | 16.5 | 31 | 131 | 368 | 58.0 | 200 | 1035 |

**Table 8.—Relative solubility of potassium in soil from the New Jersey Experiment Station, as influenced by various nitrogenous fertilizers.**

| Plat No. | Source of nitrogen | pH | Relative Solubility of Potassium | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Displaced solution | Extracts | | | Neubauer | Leaching | Average |
| | | | | $H_2O$ | $H_2CO_3$ | $HNO_3$ | | | |
| | | | Unlimed Sections | | | | | | |
| 4A | Minerals only | 4.85 | 148 | 106 | 97 | 87 | 88 | 86 | 102 |
| 7A | No fertilizer | 4.60 | 87 | 42 | 40 | 42 | 49 | 53 | 45 |
| 8A | ½ Sodium nitrate | 5.25 | 74 | 58 | 79 | 81 | 78 | 75 | 74 |
| 9A | Sodium nitrate | 5.20 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 10A | Calcium nitrate | 5.15 | 44 | 63 | 76 | 80 | 78 | 81 | 69 |
| 11A | Ammonium sulfate | 4.25 | 153 | 122 | 151 | 86 | 80 | 51 | 107 |
| 12A | Calcium cyanamid | 5.35 | 54 | 58 | 70 | 69 | 91 | 121* | 68 |
| 13A | Dried blood | 4.75 | 41 | 95 | 97 | 97 | 30 | 90 | 80 |
| | | | Limed Sections | | | | | | |
| 4B | Minerals only | 6.45 | 146 | 88 | 119 | 87 | 86 | 88 | 102 |
| 7B | No fertilizer | 6.35 | 53 | 43 | 64 | 47 | 62 | 84 | 59 |
| 8B | ½ Sodium nitrate | 6.35 | 72 | 110 | 119 | 95 | 100 | 93 | 98 |
| 9B | Sodium nitrate | 6.55 | 83 | 87 | 100 | 97 | 128 | 149 | 107 |
| 10B | Calcium nitrate | 6.50 | 14* | 91 | 60 | 42 | 42 | 89 | 65 |
| 11B | Ammonium sulfate | 6.20 | 51 | 82 | 87 | 95 | 84 | 110 | 85 |
| 12B | Calcium cyanamid | 6.35 | 65 | 45 | 60 | 59 | 55 | 166* | 57 |
| 13B | Dried blood | 6.05 | 53 | 31 | 44 | 41 | 26 | 135* | 38 |

* Not included in average.

the relative availability of the potassium in the various plats It seems, however, that the ammonium sulfate plat gave relatively large amounts of available potassium, as indicated by potassium solubility in the soil solution, water extract, and carbonic acid extract. This plat, however, has a low availability as indicated by the nitric acid extract, the leaching method, and by the Neubauer seedling test. All of these methods are much more drastic in effect than are the first group of methods. The sodium nitrate plat, on the other hand, shows a relatively high potassium availability by the latter group of methods and a low availability by the first group. For example, plats 9A and 11A, receiving sodium nitrate and ammonium sulfate, respectively, had reactions of pH 5.20 and pH 4.25, while the displaced solutions contained 77.2 p.p.m. and 117.5 p.p.m. of potassium, the water extracts 54.0 p.p.m. and 66.0 p.p.m., the nitric acid extracts 324 p.p.m. and 278 p.p.m., the leachings 44.6 p.p.m. and 22.8 p.p.m. and the uptake of potassium by the seedlings in the Neubauer method was 14.0 mgm. and 11.4 mgm. Thus, giving plat 9A the relative value of 100 and considering the first group of methods mentioned above, the average relative availability of potassium in plat 11A is 138, while for the nitric acid extract and Neubauer test the average relative figure is 72. The high content of water-soluble potassium in plat 11A and the comparatively low availability in this plat as evidenced by the nitric acid extract, the leaching experiment and Neubauer test indicates that the high acidity of the soil due to nitrification of the ammonium sulfate caused a greater amount of potassium to come into the soil solution. There was consequently an increase in leaching and removal of potassium, with a reduction in the potentially available supply, as indicated by the other methods. There is not much difference in potassium availability of plats 8A, 10A, 12A, and 13A, when the average of all methods is considered, all of them giving from 70 per cent to 80 per cent as much potassium as plat 9A.

The influence of the application of lime on the availability of potassium is not definitely conclusive from the results obtained. Liming increased the availability of potassium in three plats, decreased it in four, and had no apparent effect on the check plat. Plats on which increases occurred are plats 7B, 8B, and 9B, receiving no fertilizer and one-half sodium nitrate and the regular amount of sodium nitrate, respectively. The decrease in availability on plat 11B as compared with plat 11A is due to the decrease of water-soluble potassium. The average relative figure for the displaced solution and the water and carbonic acid extracts of plat 11A is 142, while for plat 11B, the figure is 73; the corresponding figures for the nitric acid extracts, Neubauer tests, and continued leaching experiment are 72 and 96. Liming corrected the high acidity of plat 11A, and thus removed the cause for the high water-soluble potassium content of plat 11A, and left more potassium in the soil which was available by the latter methods. The largest decrease in availability due to liming occurred on plat 13B, receiving dried blood. The average relative figure decreased from 80 for plat 13A to 38 for plat 13B, a decrease of 53 per cent due to liming. The decreases in plats 4B, 10B, and 12B may be attributed to the additional calcium present in soluble form and repressing potassium availability. For some reason, this repression due to calcium does not occur in plats receiving sodium nitrate. These plats are as high in soluble calcium as plats 10B and 12B, yet a depression due to the presence of calcium is not evident. The explanation for the relatively high availability of potassium in both the limed and unlimed sodium nitrate plats, as compared to that of the calcium nitrate plat, is not evident. It may be that sodium, being so similar in chemical properties to potassium, tends to make it more available.

### Calcium Availability

THE CONCENTRATION of calcium in the displaced solutions and various extracts was determined, and the results are presented in Table 7. There was very little difference in the water-soluble calcium of the unlimed sections, if we except plat 7A, which never received any fertilizer and in which the amount of soluble calcium was quite low. Calcium removal due to plant growth has been less on plats 11A and 4A than on any of the other plats. Plats receiving sodium nitrate were as high in available calcium as plats receiving calcium nitrate or calcium cyanamid. The high acidity of plats 11A and 13A is undoubtedly the reason why these soils are so high in water-soluble calcium, and as in the case of potassium, this high concentration of easily soluble calcium was at the expense of the potentially available supply. This is brought out by a study of the nitric acid extracts. The concentration of calcium in the acid extract of plat 11A was lower than in that of any other plat, being 135 p.p.m., as compared with 395 p.p.m. in the acid extract of the check plat. The nitric acid extract of plat 13A, which contained 305 p.p.m., indicated a considerable depletion of the calcium supply, although this depletion was by no means as pronounced as that in the case of plat 11A. There was no difference between the acid extracts of plats 4A, 8A, and 9A, which receive all their calcium fertilization in superphosphate (acid phosphate). Plats 10A and 12A, receiving calcium salts of nitrogen, gave nitric acid extracts containing 500 p.p.m. and 550 p.p.m., concentration of calcium much higher than in any other unlimed plat. Liming greatly increased the amounts of soluble calcium in all plats.

## ALABAMA EXPERIMENT STATION PLATS

### History of Plats

THE SOURCES of nitrogen plats at the Alabama Station have been described in detail by Pierre (34). They were started in 1911 for the purpose of comparing sodium nitrate, ammonium

**Table 9.—Solubility of inorganic phosphate in soil from the Alabama Experiment Station as influenced by various nitrogenous fertilizers.**

| Plat No. | Source of nitrogen | pH | Displaced solution | Extracts | | | Absorbed in Neubauer test | Average |
|---|---|---|---|---|---|---|---|---|
| | | | | $H_2O$ | $H_2CO_3$ | $HNO_3$ | | |
| | | | p.p.m. | p.p.m. | p.p.m. | p.p.m. | mgm. | |
| 1 | Sodium nitrate | 5.60 | 0.08 | 2.50 | 3.51 | 78.8 | 5.0 | --- |
| 2 | Calcium cyanamid | 5.85 | 0.05 | 4.40 | 5.20 | 101.9 | 5.5 | --- |
| 3 | Check | 5.45 | 0.05 | 2.30 | 3.04 | 90.6 | 4.1 | --- |
| 4 | Ammonium sulfate | 4.55 | 0.06 | 1.15 | 1.94 | 74.9 | 3.1 | --- |
| | | | Relative Solubility | | | | | |
| 1 | Sodium nitrate | 5.60 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2 | Calcium cyanamid | 5.85 | 62 | 176 | 164 | 130 | 110 | 128 |
| 3 | Check | 5.45 | 62 | 92 | 86 | 115 | 83 | 87 |
| 4 | Ammonium sulfate | 4.55 | 75 | 44 | 55 | 95 | 62 | 66 |

sulfate, and calcium cyanamid. All plats received fertilizer at the rate of 160 pounds of superphosphate (acid phosphate), 100 pounds of kainit, and 150 pounds sodium nitrate or its nitrogen equivalent per acre per crop. Two crops have been grown each year. Since 1925, only one crop has been fertilized, the plats receiving their fertilizer in the fall for the winter crop of oats. Samples of the plats were collected in January, 1927.

### Phosphate Availability

THE RESULTS of the study of inorganic phosphate availability in these soils are presented in Table 9. The results show that ammonium sulfate increased the acidity of the soil from pH 5.45 in plat 3 to pH 4.55 in plat 4. This increased acidity was accompanied by a decrease in the solubility of inorganic phosphate. The differences in phosphate concentration of the displaced solutions were not significant, since the amounts present were too small. The results obtained with other methods, however, indicate a marked reduction in phosphate solubility following the use of ammonium sulfate. Thus, the water extract of the check plat contained 2.30 p.p.m. of inorganic phosphate, while plat 4, receiving ammonium sulfate, contained only 1.15 p.p.m. This is also shown by a comparison of the phosphate absorption by wheat seedlings grown in soil from the check plat and from that receiving ammonium sulfate. Plat 3, receiving minerals only, supplied 4.1 mgm. of phosphate to the seedlings in the Neubauer tests, while plat 4, receiving ammonium sulfate and minerals, supplied but 3.1 mgm.

Sodium nitrate did not materially influence the acidity, and all results show that the solubility of phosphate was slightly increased on the plat receiving this source of nitrogen, when compared with the check plat. The figures for water extracts, carbonic acid extracts, and Neubauer tests for plat 1, receiving sodium nitrate, and 3, receiving minerals only, were 2.5 p.p.m. and 2.3 p.p.m., 3.51 and 3.04 p.p.m., and 5.0 and 4.1 mgm. All three methods indicate a greater availability in plat 1, but the difference in all cases is very small.

Water, carbonic acid, and nitric acid extracts from the plat receiving calcium cyanamid were higher in inorganic phosphorus than those from any other plat, and at the same time there was a considerable decrease in acidity due to the use of this fertilizer. Neubauer tests, however, do not indicate a very significant increase in the availability of phosphate from this plat when compared with those receiving sodium nitrate.

### Potassium Availability

THE RESULTS of the potassium and calcium studies are presented in Table 10. The most outstanding point in connection with the potassium availability of these soils is the high concentration of potassium in the displaced solutions of the plats receiving minerals only and ammonium sulfate, when compared

**Table 10.—Solubility of potassium and calcium in soil from the Alabama Experiment Station, as influenced by various nitrogenous fertilizers.**

| Plat No. | Source of nitrogen | Potassium | | | | | | Calcium | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Displaced solution | Extracts | | | Absorbed in Neubauer test | Average | Displaced solution | Extracts | |
| | | | $H_2O$ | $H_2CO_3$ | $HNO_3$ | | | | $H_2O$ | $HNO_3$ |
| | | p.p.m. | p.p.m. | p.p.m. | p.p.m. | mgm. | | p.p.m. | p.p.m. | p.p.m. |
| 1 | Sodium nitrate | 10.8 | 17.5 | 22.1 | 70.2 | 8.4 | --- | 42 | 14.4 | 248 |
| 2 | Calcium cyanamid | 9.8 | 10.3 | 16.8 | 61.7 | 8.7 | --- | 60 | 26.1 | 465 |
| 3 | Check | 22.4 | 12.7 | 19.2 | 59.4 | 6.8 | --- | 28 | 13.2 | 156 |
| 4 | Ammonium sulfate | 26.3 | 16.8 | 22.5 | 50.2 | 5.9 | --- | 71 | 8.8 | 72 |
| | | Relative Solubility | | | | | | | | |
| 1 | Sodium nitrate | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2 | Calcium cyanamid | 91 | 59 | 76 | 88 | 103 | 83 | 143 | 181 | 187 |
| 3 | Check | 207* | 73 | 87 | 84 | 81 | 81 | 67 | 91 | 63 |
| 4 | Ammonium sulfate | 243* | 96 | 104 | 71 | 70 | 85 | 169 | 61 | 29 |

* Not included in average.

with the plats receiving sodium nitrate and calcium cyanamid. The displaced solution of the check, plat 3, contained 22.4 p.p.m., that of the ammonium sulfate plat contained 26.3 p.p.m., while those from plats 1 and 2, receiving sodium nitrate and calcium cyanamid, respectively, contained but 10.8 p.p.m. and 9.8 p.p.m. The potassium contents of the water and carbonic acid extracts of plats 1 and 4 were not significantly different, but were slightly higher than those of the check plat. These same methods indicate a relatively low availability of potassium in plat 2, receiving calcium cyanamid. The nitric acid extracts and Neubauer tests indicate a greater supply of available potassium in plat 1 than in plat 4. The acidity developed incident to nitrification of the ammonium sulfate applied to plat 4 was sufficient to bring a great deal of both potassium and calcium into the displaced solution, but this was evidently at the expense of the readily soluble portion of the soil compounds containing these two elements, as indicated by the composition of the nitric acid extracts.

The work on this soil, shows that the use of acid-forming nitrogenous fertilizer increases the water-soluble potassium and causes a decrease in the amount of potassium potentially available, while the use of physiologically basic nitrogenous fertilizers carrying sodium and calcium results in a decrease in water-soluble potassium and a conservation of the potentially available supply.

## RHODE ISLAND EXPERIMENT STATION PLATS

### History of Plats

THE SOURCES of nitrogen experiment of the Rhode Island Station was started in 1893 on a Merrimac silt loam. The fertilizer and liming histories of these plats are given in detail by Hartwell and Damon (19). All plats received the same amounts of nitrogen, but plats 23 and 25 received ammonium sulfate and plats 27 and 29 received sodium nitrate. Up to 1915, plats 23 and 27 had received no lime, but by that year, plat 23 had developed such an acidity that liming of this plat was necessary in order to permit plant growth. Since that time, 4,000 pounds of calcium oxide per acre have been applied. The corresponding plat, 27, has never received any lime. Plats 25 and 29 have received lime since the experiment started, but in different amounts since 1914, namely; plat 25 received 8,000 pounds of calcium oxide per acre while plat 29 received but 3,000 pounds. No regular rotation has been practiced on the plats. Superphosphate (acid phosphate) and muriate or sulfate of potash have been added as necessary, the annual applications averaging 112 pounds of phosphoric acid and 105 pounds of potash per acre. All plats have always received the same amounts of phosphoric acid, and also of potash. Samples of the plats were collected in the spring of 1926, two weeks after the application of 110 pounds of phosphoric acid, 100 pounds of potash, and, to the limed plats, 1,500 pounds of calcium oxide per acre.

**Table 11.—Solubility of inorganic phosphate in soil from the Rhode Island Experiment Station, as influenced by various nitrogenous fertilizers.**

| Plat No. | Source of nitrogen | pH | Displaced solution | Extracts | | | Absorbed in Neubauer test | Average |
|---|---|---|---|---|---|---|---|---|
| | | | | $H_2O$ | $H_2CO_3$ | $HNO_3$ | | |
| | | | p.p.m. | p.p.m. | p.p.m. | p.p.m. | mgm. | |
| 23 | Ammonium sulfate | 4.80 | 0.34 | 0.32 | 0.63 | 495 | 7.2 | --- |
| 25 | Ammonium sulfate, Lime | 6.10 | 0.40 | 0.36 | 0.68 | 421 | 8.4 | --- |
| 27 | Sodium nitrate | 5.35 | 0.50 | 0.38 | 0.72 | 455 | 7.4 | --- |
| 29 | Sodium nitrate, Lime | 6.15 | 0.52 | 0.56 | 0.84 | 387 | 8.6 | --- |
| | | | Relative Solubility | | | | | |
| 23 | Ammonium sulfate | 4.80 | 68 | 84 | 87 | 109 | 97 | 89 |
| 25 | Ammonium sulfate, Lime | 6.10 | 80 | 95 | 94 | 92 | 113 | 95 |
| 27 | Sodium nitrate | 5.35 | 100 | 100 | 100 | 100 | 100 | 100 |
| 29 | Sodium nitrate, Lime | 6.15 | 104 | 148 | 117 | 83 | 116 | 116 |

## Phosphate Availability

THE SOIL reaction and the actual and relative solubility of inorganic phosphate in these plats are given in Table 11. In most cases, the differences in phosphate solubility between plats receiving ammonium sulfate and sodium nitrate were quite small, but there appeared to be slightly more easily soluble phosphate in the plats which received sodium nitrate. The carbonic acid extract of plat 25, for example, contained 0.68 p.p.m., as compared with 0.84 p.p.m. in that of plat 29, although the two soils had the same reaction. There were no significant differences in the results of the Neubauer tests of plats receiving sodium nitrate and ammonium sulfate. All methods except the nitric acid extract showed increases in phosphate availability due to the use of lime. In this connection, it must be remembered that plat 23, where the greatest increase would be expected, had received a large amount of lime, and the increase due to the use of this lime would counteract the decrease due to the use of ammonium sulfate.

## Potassium Availability

THE RESULTS of the study of potassium availability, together with the results of the study of calcium, are presented in Table 12. All methods except the nitric acid extract, which showed no difference between the plats receiving sodium nitrate and ammonium sulfate, indicated an increase in potassium availability on the plats which received sodium nitrate. This soil is therefore, different from the soils of the New Jersey and Alabama Stations, where plats receiving ammonium sulfate contained much more water-soluble potassium than those receiving sodium nitrate. The explanation of the difference may lie in the fact that in the plats of this Station, the ammonium sulfate plats received a great deal more lime than the sodium nitrate plats, while this is not true of the plats of the other two Stations. The calcium content was consequently very much higher in the soil solution of the ammonium sulfate plats than in the soil solution of the sodium nitrate plats. For example, the displaced solution of plat 23 contained 423 p.p.m. of calcium, while that of plat 27 contained but 260 p.p.m. This larger calcium content in plat 23 apparently caused a repression of potassium availability in spite of the increase in the acidity of this plat. This explanation is supported by a study of the effect of liming on potassium availability in plats 25 and 29. All methods agree in indicating a decreased availability in both sodium nitrate and ammonium sulfate plats following the use of the larger amount of lime. Thus, liming decreased the average relative potassium availability from 100 to 61 on the plats receiving sodium nitrate and from 83 to 51 on the plats receiving ammonium sulfate.

**Table 12.—Solubility of potassium and calcium in soil from the Rhode Island Experiment Station, as influenced by various nitrogenous fertilizers.**

| Plat No. | Source of Nitrogen | Potassium | | | | | | Calcium | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Displaced solution | Extracts | | | Absorbed in Neubauer test | Average | Displaced solution | Extracts | | |
| | | | $H_2O$ | $H_2CO_3$ | $HNO_3$ | | | | $H_2O$ | $H_2CO_3$ | $HNO_3$ |
| | | p.p.m. | p.p.m. | p.p.m. | p.p.m. | mgm. | | p.p.m. | p.p.m. | p.p.m. | p.p.m. |
| 23 | Ammonium sulfate | 67.6 | 38.2 | 61 | 150 | 15.5 | --- | 423 | 145 | 124 | 358 |
| 25 | Ammonium sulfate, Lime | 37.2 | 16.3 | 48 | 117 | 7.8 | --- | 495 | 125 | 278 | 770 |
| 27 | Sodium nitrate | 94.6 | 51.8 | 73 | 152 | 18.4 | --- | 260 | 89 | 152 | 370 |
| 29 | Sodium nitrate, Lime | 43.3 | 24.9 | 52 | 114 | 11.9 | --- | 273 | 82 | 252 | 823 |
| | **Relative Solubility** | | | | | | | | | | |
| 23 | Ammonium sulfate | 72 | 74 | 84 | 100 | 84 | 83 | 163 | 163 | 82 | 97 |
| 25 | Ammonium sulfate, Lime | 39 | 31 | 66 | 77 | 42 | 51 | 190 | 140 | 183 | 208 |
| 27 | Sodium nitrate | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 29 | Sodium nitrate, Lime | 46 | 48 | 71 | 75 | 65 | 61 | 105 | 92 | 166 | 225 |

## PENNSYLVANIA EXPERIMENT STATION PLATS

### History of Plats

THE SOIL used in this portion of the study was taken from the long-continued fertilizer experiment of the Pennsylvania Experiment Station. The history of these plats is reported in various publications from that Station (17). Plats receiving minerals and three amounts of dried blood, sodium nitrate, and ammonium sulfate, three plats receiving minerals only, and two plats receiving no fertilizer were used. All plats except the last two received minerals at the rate of 48 pounds of phosphoric acid in dissolved boneblack and 100 pounds of potash in muriate of potash per acre. The three nitrogenous fertilizers were applied at three rates, so that for each source of nitrogen there was a plat which received 24 pounds of nitrogen, one which received 48 pounds of nitrogen, and one which received 72 pounds of nitrogen. All applications of dried blood and sodium nitrate increased the yield, but ammonium sulfate decreased it after the first few applications. The relative increase or decrease depended on the amount of fertilizer used. The results of the study of these plats are given in Tables 13 and 14.

### Phosphate Availability

THESE SOILS were exceedingly low in soluble inorganic phosphate content, and very little can be learned from a study of the extracts. The concentration of phosphate in nitric acid extracts of plats which had received sodium nitrate was considerably less than in those from any other fertilized plats. The unusually low concentration of soluble phosphate in this soil is shown by the fact that the nitric acid extracts of these soils contained from 10 to 20 p.p.m. of phosphate, while those of soils from New Jersey contained from 200 to 300 p.p.m., from Alabama, from 75 to 100 p.p.m., and from Rhode Island, from 400 to 500 p.p.m.

The results of the Neubauer tests indicate a relative availability different from that indicated by the various extracts. The plats which received ammonium sulfate are considerably the lowest in phosphate availability as determined by this method, while those which received sodium nitrate are the highest. This soil furnished nearly as much phosphate to wheat seedlings as the other soils mentioned above. The difference in phosphate availability as indicated by the two groups of methods used in the study of this soil indicates that in some soils, at least, solubility methods do not indicate the amount of phosphate available for plant growth. In the study of the soils from the other stations, the agreement in most cases between solubility and seedling methods is very good, however, and it is possible that there are in this soil factors influencing phosphate solubility which are not present in a majority of soils. Any definite conclusions relative to the effect of the various sources of nitrogen on phosphate

**Table 13.—Solubility of phosphate, potassium and calcium in soil from the Pennsylvania Experiment Station, as influenced by various nitrogenous fertilizers.**

| Plat No. | Source of Nitrogen | Rate of Nitrogen Fertilization | pH | Phosphate* | | Potassium | | | | Calcium | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Inorganic $PO_4$ $HNO_3$ Extract | Absorbed in Neubauer test | Extracts $H_2O$ | Extracts $H_2CO_3$ | Extracts $HNO_3$ | Absorbed in Neubauer test | Extracts $H_2O$ | Extracts $HNO_3$ |
| | | | | p.p.m. | mgm. | p.p.m. | p.p.m. | p.pm. | mgm. | p.p.m. | p.p.m. |
| 17 | Dried blood | 24 lbs. N | 4.95 | 16.1 | 7.7 | 15.5 | 45.0 | 153 | 18.1 | 7.2 | 315 |
| 19 | Dried blood | 48 lbs. N | 5.05 | 16.0 | 6.6 | 15.8 | 46.3 | 155 | 17.6 | 7.6 | 390 |
| 21 | Dried blood | 72 lbs. N | 5.05 | 13.2 | 8.3 | 15.6 | 48.7 | 148 | 20.3 | 5.2 | 305 |
| 26 | Sodium nitrate | 24 lbs. N | 5.30 | 15.5 | 8.1 | 9.1 | 33.3 | 163 | 16.2 | 10.0 | 585 |
| 27 | Sodium nitrate | 48 lbs. N | 5.35 | 11.4 | 8.0 | 9.2 | 28.3 | 160 | 16.3 | 9.1 | 525 |
| 28 | Sodium nitrate | 72 lbs. N | 5.45 | 11.0 | 12.1 | 8.7 | 33.3 | 164 | 16.7 | 9.2 | 545 |
| 30 | Ammonium sulfate | 24 lbs. N | 4.85 | 17.0 | 5.5 | 24.5 | 50.0 | 118 | 13.7 | 7.6 | 225 |
| 31 | Ammonium sulfate | 48 lbs. N | 4.45 | 19.2 | 5.5 | 29.9 | 45.5 | 123 | 11.7 | 12.0 | 75 |
| 32 | Ammonium sulfate | 72 lbs. N | 4.40 | 21.6 | 5.7 | 29.4 | 52.6 | 125 | 10.6 | 10.8 | 45 |
| 15 | Minerals only | | 5.35 | 15.5 | 6.9 | 19.4 | 40.5 | 149 | 18.3 | 8.0 | 580 |
| 25 | Minerals only | | 5.20 | 17.8 | 6.5 | 15.4 | 41.6 | 150 | 13.3 | 9.2 | 570 |
| 29 | Minerals only | | 5.25 | 18.8 | 6.5 | 16.9 | 44.8 | 152 | 18.8 | 10.4 | 500 |
| 14 | No fertilizer | | 5.35 | 5.0 | 3.0 | 6.1 | 19.0 | 120 | 12.1 | 10.8 | 545 |
| 24 | No fertilizer | | 5.30 | 6.1 | 2.8 | 6.4 | 28.9 | 123 | 8.8 | 6.0 | 514 |

* Water and carbonic acid extracts contained only traces of inorganic phosphate and consequently are not reported here.

**Table 14.—Relative solubility of phosphate and potassium in soil from the Pennsylvania Experiment Station, as influenced by various nitrogenous fertilizers.**

| Plat No. | Source of nitrogen | Rate of Nitrogen Fertilization | pH | $PO_4$ | | Potassium | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $HNO_3$ Extract | Neubauer test | Extracts | | | Neubauer test | Average |
| | | | | | | $H_2O$ | $H_2CO_3$ | $HNO_3$ | | |
| 17 | Dried blood | 24 lbs. N | 4.95 | 146 | 64 | 178 | 135 | 93 | 108 | 128 |
| 19 | Dried blood | 48 lbs. N | 5.05 | 146 | 54 | 181 | 139 | 94 | 106 | 130 |
| 21 | Dried blood | 72 lbs. N | 5.05 | 120 | 69 | 179 | 146 | 92 | 122 | 135 |
| 26 | Sodium nitrate | 24 lbs. N | 5.30 | 141 | 67 | 104 | 100 | 100 | 97 | 100 |
| 27 | Sodium nitrate | 48 lbs. N | 5.35 | 104 | 67 | 105 | 85 | 98 | 98 | 96 |
| 28 | Sodium nitrate | 72 lbs. N | 5.45 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 30 | Ammonium sulfate | 24 lbs. N | 4.85 | 155 | 46 | 282 | 150 | 72 | 82 | 144 |
| 31 | Ammonium sulfate | 48 lbs. N | 4.45 | 173 | 46 | 342 | 136 | 75 | 70 | 156 |
| 32 | Ammonium sulfate | 72 lbs. N | 4.40 | 196 | 55 | 336 | 158 | 76 | 63 | 158 |
| 15 | Minerals only | | 5.35 | 141 | 57 | 223 | 122 | 91 | 110 | 136 |
| 25 | Minerals only | | 5.20 | 163 | 53 | 176 | 125 | 79 | 79 | 115 |
| 29 | Minerals only | | 5.25 | 171 | 54 | 194 | 135 | 92 | 112 | 133 |
| 14 | No fertilizer | | 5.35 | 45 | 37 | 71 | 57 | 73 | 72 | 68 |
| 24 | No fertilizer | | 5.30 | 55 | 46 | 73 | 87 | 75 | 53 | 72 |

availability in this soil cannot be drawn, because it is impossible to say which of the methods is the more accurate in its indication of the relative availability.

### Potassium Availability

THE APPLICATION of sodium nitrate caused a reduction of water-soluble potassium below the concentration in the check plat, while the use of ammonium sulfate caused a marked increase. The water extracts of the dried blood plats contained approximately the same amounts of potassium as the plats which received minerals only. For example, using plat 28, receiving 72 pounds of nitrogen in sodium nitrate, as the standard of comparison with a relative availability of 100, the water extracts of plats 32, 29, 21, and 24, receiving 72 pounds of nitrogen in ammonium sulfate, minerals only, 72 pounds of nitrogen in dried blood, and no fertilizer, respectively, indicate relative potassium availabilities of 336, 194, 179, and 73. The sodium applied in the sodium nitrate had a repressive effect upon water-soluble potassium, while the marked increase in acidity due to the use of ammonium sulfate caused much more potassium to come into solution. The spread in relative concentration of potassium in the carbonic acid extracts is not nearly so great, the figures being 158, 135, 146, and 87. This indicates that the increase in water-soluble potassium in the ammonium sulfate and dried blood plats is at the expense of the potentially available supply. This fact begins to be apparent with a small increase in the strength of the extractant, and is brought out still more clearly by a study of the nitric acid extracts. In these extracts, the relative availabilities are 76 for the ammonium sulfate plat, 92 for the plat which received minerals only, 92 for the dried blood plat, and 75 for the plat which received no fertilizer. These results indicate a marked reduction in potassium availability in the ammonium sulfate plat. In fact, the amount of nitric acid-soluble potassium is the same in plat 32, receiving minerals and the largest amount of ammonium sulfate as in plat 24, receiving no fertilizer, although the water extracts of the former contained 4.5 times as much potassium as the latter. The reduction in potassium availability in the ammonium sulfate plats is again emphasized by a study of the results of the Neubauer tests, where these plats furnished less potassium to the wheat seedlings than any other fertilized plats, and but little more than the plats which had never received any potassium fertilizer.

These results again show very clearly that the development of acidity following the nitrification of ammonium sulfate causes the solution of a considerable amount of potassium-containing materials in the soil, but that this increase is at the expense of the potentially available supply. Sodium nitrate decreases the amount of water-soluble potassium; this tends to conserve the available supply, as indicated by nitric acid extracts and Neubauer tests.

## Calcium Availability

THE EFFECT of the various fertilizer treatments on calcium availability is very similar to their effect on potassium availability. The plats which received dried blood are the only ones which gave water extracts significantly low in calcium, but the results of the nitric acid extracts indicate a different relative availability. The difference in the acidity of the plats receiving sodium nitrate, dried blood, and ammonium sulfate is clearly reflected in the difference in nitric acid-soluble calcium present in the various plats. Thus, plat 28, receiving sodium nitrate, contained the same amount of acid-soluble calcium as the check and unfertilized plats. Dried blood caused an increase in acidity of plat 21 from pH 5.25, the reaction of the check, plat 29, to pH 5.05, and a reduction in acid-soluble calcium from 500 p.p.m. to 305 p.p.m. Ammonium sulfate increased acidity of plat 32 to pH 4.40, and caused the removal of practically all of the acid-soluble calcium.

## NORTH CAROLINA EXPERIMENT STATION PLATS

THE PLATS used in this study are part of the fertilizer test with flue-cured tobacco at Oxford. The history and fertilizer treatment are given in detail by Moss and others (29). The experiment was started in 1913. Since that time the plats have been in rotations that included legumes turned under and small grains which received a uniform application of sodium nitrate on all plats. Tobacco was the only crop in the rotation which received different sources of nitrogen.

As in most of the preceding experiments, the results reported in Table 15 show that, as compared with sodium nitrate, the use of ammonium sulfate without lime increased soil acidity and reduced the availability of phosphate. At the same time, it increased the amount of water-soluble potassium, but this apparently was at the expense of the potentially available supply, as indicated by the Neubauer method. When lime was used, the differences in availability of phosphate were small.

**Table 15.—Solubility of inorganic phosphate and potassium in soil from the North Carolina Experiment Station, as influenced by various nitrogenous fertilizers.**

| Source of Nitrogen | pH | Phosphate | | Potassium | |
|---|---|---|---|---|---|
| | | Extract Water | Absorbed in Neubauer test | Water Extract | Absorbed in Neubauer test |
| | | p.p.m. | mgm. | p.p.m. | mgm. |
| Sodium nitrate | 5.15 | 11.6 | 8.3 | 45.8 | 19.9 |
| Ammonium sulfate | 4.80 | 2.1 | 5.4 | 82.5 | 12.6 |
| Sodium nitrate—Lime | 6.35 | 14.0 | 7.6 | 41.2 | 20.0 |
| Ammonium sulfate—Lime | 5.95 | 6.8 | 7.1 | 43.4 | 9.6 |

## DISCUSSION

### Phosphate Availability

THE INFLUENCE of any nitrogenous fertilizer on the availability of phosphate in a given soil is determined very largely by its influence on soil reaction and on the amount and nature of the cations present in the soil solution and exchange complex of the soil. These two factors, reaction and influence of the cation, will be considered separately in the following discussion of phosphate availability. Frequently the two factors cannot be separated, for any treatment that alters the soil reaction must alter the cation relationships. For present purposes, however, any influence of reaction on cation relationship will be considered under the discussion of reaction, except that the influence of liming will receive separate consideration.

#### Influence of reaction

PIERRE (35) has recently made an extensive study of the influence of various nitrogenous fertilizers on the soil reaction, and in his paper gives a review of the results of other investigators. The results of these studies have shown beyond question that sodium nitrate, calcium nitrate, and calcium cyanamid decrease the acidity of the soil, while ammonium salts and urea have the opposite effect. The work reported in this paper also shows the same thing. Thus, in the New Jersey unlimed soils (Table 3) the use of sodium nitrate resulted in a change in reaction from pH 4.85 on the check, plat 4A, to pH 5.20 on plat 9A, receiving the regular amount of sodium nitrate, while the use of ammonium sulfate on plat 11A caused an increase in acidity to pH 4.25. In the experiment conducted by the Rhode Island Experiment Station, 4,000 pounds of calcium oxide have been applied to plat 23, receiving ammonium sulfate, while no lime has ever been applied to plat 27, receiving sodium nitrate. In spite of the addition of this large amount of calcium oxide plat 23 had a reaction of pH 4.80 while plat 27 had a reaction of pH 5.35.

A number of investigators have found that soil reaction has a marked influence on phosphate availability. McGeorge (26) found in work with the highly ferruginous soils of the Hawaiian Islands that no soil with a pH value above 6.3 showed any lack of available phosphate, while with one exception all soils with a pH value below that figure gave a response to phosphatic fertilization. Vanstone (47), working with a method in which the availability of phosphate was estimated by determining the ratio between phosphate soluble in a dilute solution of citric acid and the total phosphate content of the soil, found that the availability of phosphate in non-acid soils was much higher than in acid soils. Evidence secured by other workers is of the same general nature. The results secured in the present study show essentially the same thing. On the New Jersey soil (Tables 3 and 5) plats 4A, 9A, and 11A, receiving minerals only, sodium nitrate, and ammonium sulfate, respectively, had pH values of 4.85, 5.20, and

4.25, and gave water extracts which contained 1.12 p.p.m., 3.30 p.p.m., and 0.40 p.p.m. of inorganic phosphate. The amounts of phosphate absorbed by wheat seedlings in the Neubauer tests of these plats were 5.3 mgm., 11.1 mgm., and 2.9 mgm., indicating large differences in availability to plant seedlings as well as in solubility. These results show a very clear correlation between decreased acidity and increased phosphate solubility in the case of plat 9A, receiving sodium nitrate, and between increased acidity and decreased phosphate availability in the case of plat 11A, receiving ammonium sulfate.

This reciprocal relation between reaction and phosphate availability is not so clear in the case of the Rhode Island soils, but here the different applications of lime make a correlation between reaction and phosphate availability difficult in these soils. It is no doubt true, however, that the relative change in availability of phosphate with a definite change in reaction will depend very largely on the character of the soil, the change being large for some soils and small for others. An illustration of this fact was noted in the following experiment, conducted for the purpose of obtaining additional data concerning the relation between acidity and phosphate and potassium solubility.

Large quantities of three soils were brought into the greenhouse, and dilute sulfuric acid or calcium carbonate added in order to produce various reactions of the soil, the amounts to be added being determined by a study of the exchangeable complex and buffer capacity of the different soils. No fertilizer of any kind was applied; and no crop was grown on the soils. Thus, the sole difference between the different samples of a single soil was due to the action of the sulfuric acid or calcium carbonate. Water-soluble phosphate and potassium were determined after sufficient time had elapsed to afford the establishment of equilibrium between the various additions and the soil. The results of the study are presented in Table 16.

**Table 16.—Influence of reaction on concentration of inorganic phosphate and potassium in 1:5 water extracts of soils.**

| Soil Type | pH | Concentration in air-dry soil | |
|---|---|---|---|
| | | K | Inorganic $PO_4$ |
| | | p.p.m. | p.p.m. |
| Miami silt loam | 4.20 | 69.5 | 0.52 |
| | 4.55 | 59.2 | 0.58 |
| | 4.90 | 42.3 | 0.66 |
| | 5.80* | 21.3 | 0.77 |
| | 6.80 | 8.8 | 0.90 |
| Greenville fine sandy loam | 4.20 | 80.7 | 0.43 |
| | 4.70 | 56.3 | 0.50 |
| | 4.90 | 33.6 | 0.64 |
| | 5.40* | 29.1 | 0.92 |
| | 6.70 | 20.5 | 1.16 |
| Brown silt loam | 4.35 | 83.3 | 15.4 |
| | 4.55 | 70.0 | 14.8 |
| | 4.80 | 61.0 | 14.0 |
| | 6.45* | 38.4 | 11.6 |
| | 6.95 | 26.2 | 9.2 |

* Untreated soil

The Miami silt loam and the Greenville fine sandy loam, with reactions and water-soluble phosphate contents of about the average for the acid soils of the humid region, show an increased phosphate solubility with decreased acidity. The brown silt loam is an alluvial soil from the Mississippi delta. Its reaction is very near the neutral point, and its contents of calcium and total, acid-soluble, and water-soluble phosphates are very high. The majority of the phosphate is undoubtedly combined with calcium as the tricalcium salt. An increase in acidity caused by the application of sulfuric acid caused an increase in the amount of water-soluble phosphate in the soil by bringing more of the tricalcium phosphate into solution. This soil is, of course, an unusual one, but serves to illustrate the point that the relation between acidity and phosphate availability is dependent to a certain degree upon the chemical system of the soil studied. In general, however, it is evident that there is a reciprocal relationship between phosphate availability and reaction. Since physiologically basic nitrogenous fertilizers decrease acidity, they increase phosphate availability, while the opposite is true of acid-forming nitrogenous fertilizers.

This influence of reaction on phosphate availability is explained in large measure by its influence on the soil bases. Comber (12) and others show that anion fixation by soils is due to chemical precipitation with cations present in the soil. In most soils of low acidity, calcium is the predominating base. The continued use of ammonium sulfate or a similar nitrogenous fertilizer causes a marked reduction in the easily soluble bases of a soil. This has been shown by various investigators. Hall (18, page 289) reports an average annual loss of calcium carbonate over a period of forty years at Rothamstead of 1,100 pounds on an ammonium sulfate plat, while the loss of the corresponding nitrate plat was only 565 pounds. Morse (28) reports, as the result of several years' study of drainage waters, an average concentration of 24.8 p.p.m. of calcium in the drainage water from a sodium nitrate plat, 36.5 p.p.m. in that from a check plat, and 54.2 p.p.m. in that from an ammonium sulfate plat. There were corresponding decreases in the calcium content of the soils studied. The present study also brings out this difference between the two fertilizers very clearly. The calcium concentrations of the 0.2 N nitric acid extracts of the New Jersey plats receiving minerals only, sodium nitrate, and ammonium sulfate were 395 p.p.m., 390 p.p.m., and 135 p.p.m.; on the Pennsylvania plats, the corresponding figures were 575 p.p.m., 545 p.p.m., and 45 p.p.m., the latter representing a decrease of over 90 per cent. in the easily soluble calcium content due to the use of ammonium sulfate.

With the removal of the easily soluble bases, more of the phosphate must combine with iron and aluminum. This is indicated by the results obtained by Howard (21) in a study of the plats of the Rhode Island Experiment Station conducted several years before the present study. In 0.2 N hydrochloric acid extracts of the plats receiving ammonium sulfate, ammonium sulfate and lime, sodium nitrate, and sodium nitrate and lime, ratios of the oxides of iron and aluminum to the oxides of calcium and magnesium are 85.0, 19.4, 47.9, and 10.0, respectively. It is evident that as soils become more acid, iron and aluminum must fix a larger percentage of the soil phosphates. The degree to which iron influences phosphate availability is dependent upon the form of iron in the soil. In this connection, Vanstone (47) cites two soils. In one of the soils, the ferric form predominated and phosphate availability was very low; in the other, the ferrous form predominated and phosphate availability was unusually high. The difference in availability was due to the difference in the solubility of the phosphates of the two forms of iron. In general, the basic phosphates of iron and aluminum are relatively insoluble and unavailable, as compared with the phosphates of more readily soluble soil bases.

### Influence of cation

THERE ARE significant differences in phosphate availability due to the cations introduced in the various physiologically basic fertilizers. Spurway (45) found that when the exchange complex of the soil was saturated with potassium, there was a very great increase in phosphate availability, and suggests that sodium would have the same influence because of the high solubility of sodium phosphate. He also studied the effect of calcium, but in this case, two soils gave very slight increases in availability while a third gave a decrease. In another study (44), he found that in five cases out of eight, the application of sodium nitrate at the rate of one ton per acre resulted in more phosphorus in water extracts than the application of the same amount of superphosphate (acid phosphate). Treatment with calcium carbonate also resulted in increased phosphate solubility, but the increases were not nearly so large as was the case with sodium nitrate. Roszmann (41), using an electro-dialyzed colloid, found that calcium clay absorbed one and one-half times as much phosphate as a sodium clay. It is to be expected, therefore, that the use of a nitrogenous fertilizer leaving a sodium residue would result in a greater availability of phosphate than the use of one leaving a calcium residue.

The work reported in this paper shows very clearly the influence of the cation carried by the nitrogenous fertilizer on phosphate availability. The results of the study of the Norfolk sandy loam presented in Table 2, gives one example of this fact. The water extract of the portion of this soil which received sodium nitrate contained 6.00 p.p.m. of inorganic phosphate, while that of the portion which received calcium nitrate contained only 2.56 p.p.m. The results of the work on these two portions of the same soil show very clearly the difference between phosphate solubility when a sodium residue is left and when a calcium residue is left, since growth on these two soils was very nearly the same, and the difference in availability can only be attributed to the residual effect of the cation carried by the nitrogenous fertilizer. The difference between these two cations is again brought out by a comparison of the soils from the New Jersey Experiment Station. Plat 9A, receiving the regular amount of sodium nitrate, had an average relative phosphate availability of 100, as shown in Table 6, while plat 10A, receiving calcium nitrate, had an availability of only 64, and plat 12A, receiving calcium cyanamid, had an availability of 70. The plats of the Alabama Experiment Station, however, show a considerably greater phosphate availability on the calcium cyanamid plat than on the sodium nitrate plat. Two explanations may be offered for the difference between the results on this soil, and those of other soils studied. First, this soil is comparatively very low in soluble material, and especially so in calcium, so that additional amounts of calcium provided in the nitrogenous fertilizer would not cause so great a repression of the reverted phosphates in the soil; second, the application of cyanamid resulted in a much greater reduction in acidity than did the application of sodium nitrate. The results of the study as a whole, however, bring out very clearly the fact that the use of physiologically basic nitrogenous fertilizers results in a considerable increase in phosphate availability, but that the degree of the increase is greater in the case of those fertilizers which leave a sodium residue than in the case of those which leave a calcium residue.

## Influence of liming

THE INFLUENCE of liming on phosphate availability may be considered as the resultant of its influence on the two factors just considered, namely; it decreases acidity and leaves a calcium residue. Plummer (39) has given a review of a great deal of the work which has been done on the influence of liming on the availability of phosphate. The general conclusion which he draws from his study is that "additions of lime, before or after applications of soluble phosphates, have greatly increased the efficiency of this phosphatic fertilizer. When insoluble calcium phosphate has been applied, it seems that applications of lime have reduced the effectiveness in a majority of cases." Parker and Tidmore (33), studying the displaced solutions and water extracts from soils from field experiments in Alabama, Illinois, Ohio, and Kentucky, found that liming increased phosphate availability in soils receiving superphosphate (acid phosphate) and basic slag, had no consistent influence in soils receiving rock phosphate, and caused a decided depression in soils receiving steamed bone meal.

Lime was applied on plats of three of the experiments reported, namely, those of the New Jersey Experiment Station, the Rhode Island Experiment Station, and the North Carolina Experiment Station. Since plats of the Rhode Island Experiment Station which received ammonium sulfate received much more lime than did those which received sodium nitrate, no conclusions can be drawn from these soils, other than that the addition of lime caused a very slight increase in phosphate availability. Liming also caused a slight increase in phosphate availability on the soils of the North Carolina Experiment Station. The soil from the New Jersey Experiment Station responded very markedly to liming. The increase in availability as indicated by the amount of water-soluble phosphate caused by the application of lime was much greater than that indicated by nitric acid extraction or by the Neubauer method. The increase due to liming depended on the nitrogenous fertilizer used. For example, liming on the sodium nitrate plat increased availability 123 per cent, on the check plat 515 per cent., and on the ammonium sulfate plat, 942 per cent., while on the dried blood plat, it decreased the availability 66 per cent. It may be concluded, then, that the influence of liming on phosphate availability is determined by a number of factors. The principal factors are source of phosphate, nature of the soil, and past fertilizer treatment particularly with regard to nitrogenous fertilization.

## POTASSIUM AVAILABILITY

THE REACTION of the soil and the relative amounts of the various cations in the soil solution and exchange complex are also the principal factors influencing potassium availability. The result of the operation of these factors on potassium availability, however, is much different from that on phosphate availability. The several methods used in this study may be divided into two groups on the basis of their indication of potassium availability. The first group is composed of the displacement method for obtaining the soil solution and extraction with water and carbonic acid; the second group is composed of the Neubauer method and extraction with nitric acid. The first group of methods indicates an increased availability due to the use of acid-forming nitrogenous fertilizers, while the second group indicates a decreased availability. This difference between the two methods may be explained by assuming that the higher acidity developed by the acid-forming fertilizers causes a greater amount of potassium to come into solution, but this increase is at the expense of the potentially available supply, as indicated by the second group of methods. The accuracy of this assumption will be brought out in the following discussion.

### Influence of reaction

VARIOUS workers have found that an increase in acidity resulted in a greater amount of water-soluble potassium in the soil. Ames (2) and Ames and Boltz (3), for example, found that the nitrification of dried blood and ammonium sulfate considerably increased the concentration of potassium in water extracts of soils. This conclusion is borne out by the data secured in this investigation. The use of ammonium sulfate has resulted in an increase in water-soluble potassium, while the opposite is true for the use of sodium nitrate. Giving to the soil of plats which received minerals only the relative value of 100, the water extracts of the New Jersey plat which received ammonium sulfate contained a potassium concentration of 104, of the Alabama plat, 117, and of the Pennsylvania plat, 171. The corresponding figures of the soil of the plats which received sodium nitrate are 67, 48, and 34. It will be noted that the degree to which the use of these fertilizers influenced potassium solubility is to a considerable extent dependent upon the nature of the soil; the Pennsylvania soil shows a very much greater effect than does the New Jersey soil.

In contrast to the above results, a decrease in acidity due to the application of lime is accompanied by a reduction in the amount of water-soluble potassium in the soil. MacIntire (25), as the result of an investigation of the effect of calcium and magnesium salts on the soil potassium, states that within practical limits of application, calcic and magnesic additions do not alter the original form of soil potassium so as to render any residual portion of it more available or beneficial to plant growth. Shedd (43) states that calcium carbonate had a depressive effect on the soluble potassium extracted by every solvent except 0.2 N nitric acid. Robinson and Bullis (40) found a marked decrease in soluble potassium following the use of calcium carbonate and calcium oxide. The results of this investigation show the same relation between potassium availability and the use of lime. Liming the ammonium sulfate plat of the New Jersey soil caused a decrease of 67 per cent in the potassium content of the displaced solution, and reduced acidity of this plat from pH 4.25 to pH 6.20. Liming the sodium nitrate plat caused a decrease in the amount of potassium in the displaced solution of 17 per cent and reduced acidity from pH 5.20 to pH 6.55.

In the soils of the various experiment stations, the differences in availability of potassium might be attributed in part to a number of factors other than reaction, such as differences in plant growth and soil variations of the various plats. In order to confine the study to the influence of reaction, the experiment described in the discussion of phosphate availability was conducted. As noted in that discussion, the difference between the various samples of a given soil can only be attributed to the different amounts of sulfuric acid or calcium carbonate added in their treatment. The data obtained in this study and presented in Table 16 show very conclusively that a development of acidity is always accompanied by an increase in amount of water-soluble potassium. The degree of this increase is dependent upon the individual soil. The use of calcium carbonate resulted in a considerable depression of potassium solubility. It is clear from the results of this experiment and the study of the long-continued experiments that an increase in acidity, whether caused by the use of sulfuric acid or acid-forming nitrogenous fertilizers, results in a considerable increase in water-soluble potassium in the soil, while the reverse is true for a decrease in acidity, whether caused by calcium carbonate or a physiologically basic nitrogenous fertilizer.

The removal of potassium from the surface soil is effected by leaching and by plant growth. Various workers have shown that a part of the potassium removed from the surface soil by leaching is fixed in the subsoil, and hence may not be considered as being rendered entirely unavailable. The increased solubility resulting in the removal of potassium by plant growth must be considered a desirable feature to a certain degree, since it tends to remove potassium from the group of factors limiting production. Bartholomew (4) and others, however, have shown that there may be a heavy or "luxury" feeding on potassium without any increase in yield or dry matter, and this must be considered as detrimental, since the potentially available supply is certainly decreased thereby.

Since there is such a great increase in water-soluble potassium following the use of ammonium sulfate or a similar fertilizer, it seems reasonable to assume that the use of these fertilizers will result in a decrease in the potentially available supply. That this assumption is correct is strongly indicated by a study of the nitric acid extracts and Neubauer tests of the various soils from long-continued field experiments. For example, nitric acid extracts and Neubauer tests of the plats of the Alabama Experiment Station indicate reductions in potassium availability of 14 per cent and 13 per cent, respectively, due to the use of ammonium sulfate, while the use of sodium nitrate resulted in increases of 19 per cent and 41 per cent. It is evident that the degree to which the potentially available supply will be exhausted due to the development of acidity will depend upon a number of factors, such as the amount originally present, the nature of the potassium-containing compounds, plant growth with particular reference to luxury feeding, and the nature of the soil as it determines leaching and fixation of potassium by absorption. So far as the action of nitrogenous fertilizers is concerned, however, it may be concluded that acid-forming fertilizers result in an increase in water-soluble potassium and a depletion of the potentially available supply, while physiologically basic fertilizers tend to conserve this supply.

### Influence of cation

BOTH SODIUM and calcium apparently have a depressing effect on the amount of water-soluble potassium in a soil. Spurway (44) has shown this in a study of water extracts secured by a procedure different from that used in this study. The depression due to calcium salts was greater than that for sodium salts. Fraps (15) states that sodium salts probably decrease potassium solubility to a certain extent. A decrease in available potassium due to the use of sodium nitrate is not evident and its use may even increase availability when crop yields are considered. Hall (18, page 98) shows this very strikingly in his report of the growth of mangolds on Barn Field, Rothamstead. Plat 5N, receiving superphosphate (acid phosphate) and sodium nitrate, produced 15.05 tons of mangolds per acre, while plat 6N, receiving superphosphate (acid phosphate), potassium sulfate, and sodium nitrate, produced 15.42 tons. The yields on plats 5A and 6A, receiving the same amount of minerals but ammonium sulfate instead of sodium nitrate, were 7.04 tons and 14.08 tons. Thus, the addition of a potassium fertilizer did not increase yields on plats receiving sodium nitrate, but doubled the yields on plats receiving ammonium sulfate. A study of the relative influence of sodium and calcium on potassium availability is afforded by the plats of the New Jersey Experiment Station. The reactions of plats 9A, 10A, and 12A, receiving sodium nitrate, calcium nitrate, and calcium cyanamid, are pH 5.20, pH 5.15, and pH 5.35, respectively, so that any differences in potassium availability cannot be attributed to differences in acidity. However, if the relative potassium availability of plat 9A is given the value of 100, the figures for plats receiving the other two fertilizers are 69 and 68. This indicates that sodium does not cause as large a depression in potassium availability as calcium, and that the two calcium-containing fertilizers are identical in their influence, as indicated by an average of the results of all methods used in this study.

## SUMMARY

THE INFLUENCE of various nitrogenous fertilizers on availability of phosphate and potassium was studied in a number of soils used in greenhouse work and in samples of soil from plats of long-continued experiments conducted by the New Jersey, Alabama, Rhode Island, Pennsylvania and North Carolina Experiment Stations. Availability was studied by the concentration of phosphate and potassium in displaced solutions and extracts of the soils, using water, 0.04 N carbonic acid, and 0.2 N nitric acid as extractants, and by the Neubauer or plant seedling methods.

Variations in availability of phosphate and potassium due to the use of the various nitrogenous fertilizers is deemed to be dependent upon the influence of these fertilizers on two principal factors, namely, reaction of the soil and the introduction of various cations carried by the fertilizers.

Ammonium sulfate, ammonium nitrate, Leunasalpeter, and urea increase soil acidity, and are termed acid-forming fertilizers. On the other hand, sodium nitrate, calcium nitrate, and calcium cyanamid decrease soil acidity and are termed physiologically basic fertilizers.

Acid-forming fertilizers caused a marked decrease in phosphate availability. They caused an increase in water-soluble potassium, but this increase was at the expense of the potentially available supply, as indicated by Neubauer tests and nitric acid extracts.

Physiologically basic fertilizers caused an increase in phosphate availability. They caused a reduction in water-soluble

potassium, but tended to conserve the potentially available supply.

The influence of the individual fertilizers, based on the study of the soils from the long-continued experiments, may be summarized as follows:

**Sodium nitrate** increased phosphate availability, due to a decrease in acidity and also to the introduction of the base sodium. It caused a reduction in potassium solubility in displaced solutions and water extracts, but nitric acid extracts and Neubauer tests indicated a conservation of the potentially available potassium.

The question as to whether or not the sodium in this fertilizer could or did substitute for part of the potassium was not investigated. Plats receiving this source of nitrogen were relatively quite high in soluble calcium.

**Ammonium sulfate** caused a marked decrease in phosphate availability, due to an increase in acidity, with a consequent impoverishment of the soil with respect to calcium and the introduction of iron and aluminum as the cations forming phosphate salts. Soils receiving this fertilizer were quite high in water-soluble potassium, but this was at the expense of the potentially available supply, as shown by a study of the nitric acid extracts and Neubauer tests. The rate at which ammonium sulfate will cause detrimental effects due to the removal of available potassium from the soil by leaching and inefficient use of potassium in plant growth depends on a number of factors, such as the amount of available potassium in the soil, the nature of the surface and subsoil, rainfall, and plant growth. It is possible that where there is a large supply of potentially available potassium and leaching is a minor factor, the use of ammonium sulfate will increase potassium availability to crops for a long period of time.

**Calcium nitrate** had about the same effect on acidity as sodium nitrate on the New Jersey soil, which was the only one where this fertilizer was used. Phosphate is not as available on the plat receiving this fertilizer as on the plat receiving sodium nitrate. This is due to the fact that calcium furnished a quantity of base for uniting with phosphate, but the compounds thus formed are not as soluble as the compounds formed when sodium is the base supplied. Calcium caused a marked repression of potassium availability in the displaced solution and water extracts, but this difference was not apparent in the nitric acid extracts and Neubauer tests. It is probable that this fertilizer salt conserves the potassium of the soil in the same manner that sodium nitrate does.

**Calcium cyanamid** caused a greater decrease in acidity than any other source of nitrogen used, due to the high content of free lime. It caused a marked increase in phosphate availability. On the New Jersey soil, it was about the same in this respect as calcium nitrate, but on the Alabama soils, all methods indicated a considerably greater amount of available phosphate in the plat receiving this fertilizer than in the plat receiving sodium nitrate. This is probably due to the considerable decrease in acidity on this plat. As in the case of calcium nitrate, the calcium in this salt repressed the solubility of potassium in water solutions, but the decrease in availability is not evident in nitric acid extracts and Neubauer tests, which indicate considerable increases due to the use of this fertilizer.

**Dried blood** caused a considerable increase in acidity, but not nearly so much as ammonium sulfate. The phosphate content of the displaced solution of the New Jersey plat was higher than that of any other unlimed plat and the Neubauer test indicated a higher availability in this plat than in any other plat except the one receiving sodium nitrate. All other methods indicated a considerably lower availability, and the general average of all methods is about the same for this source of nitrogen as for the calcium salts. The nitric acid extracts of these plats on the Pennsylvania soil contained more phosphate than those of the sodium nitrate plats, but Neubauer tests indicated that these plats contained only about two-thirds as much available phosphate. Solubility methods indicated about the same potassium availability on the New Jersey soil as they did for the sodium nitrate plat, but on the Pennsylvania soil, a considerably higher availability.

**Liming** greatly decreased acidity and caused a marked increase in phosphate availability. The results for potassium are not so consistent and it is apparent that whether liming increases or decreases potassium availability is determined by more complex factors than is the case with phosphate availability.

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