# SOIL FERTILITY STUDIES

## THE FIXATION AND AVAILABILITY OF PHOSPHATES IN SOME CEYLON SOILS

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### SUMMARY

ELEVEN soils belonging to the major soil groups of Ceylon were studied in respect of: (1) the various forms of phosphorus present in them (2) their power to fix added phosphates.

Soil phosphorus was fractionated into (*a*) readily available (*b*) alkali soluble inorganic (*c*) alkali soluble organic (*d*) acid soluble and (*e*) insoluble portions.

Most of these soils are acid in reaction and very low in readily available phosphoric acid. The neutral and slightly alkaline soils from Hingurakgoda and Jaffna respectively, have fair amounts. The reaction of a soil seems to control the amount present.

The acid soils are relatively high in both the alkali soluble fractions (b & c). An inverse relationship exists generally between the pH of these soils and their percentages of these fractions.

Iron and aluminium phosphates are regarded as the main constituents of the alkali soluble inorganic fraction. As the normal phosphates are available to plants, while other forms are not, the extent of the immediate availability of this fraction would depend on the relative amounts of these two forms.

The organic fraction, though not directly available to plants, is considered to be, on decomposition, a valuable source of phosphorus. The organic soils from Bopatalawa and Matara and the paddy soil from Gampola are relatively rich in the organic fraction. Liming the soils helps its mineralization.

Acid soluble phosphorus is found to be highest in the Jaffna and Nalanda soils of limestone origin and lowest in the Bopatalawa soil. A positive correlation exists between the reaction of a soil and the percentage of this fraction.

The Nalanda soil has the highest amount of insoluble phosphorus.

The soils studied vary very greatly in their power to fix added phosphorus. The laterite Bopatalawa soil shows the highest fixing power and the non-lateritic Jaffna soil the lowest. Sub-soils fix phosphates to a greater extent than their surface soils. Fixing power of organic matter seems to be low.

Practical suggestions to increase availability of soil phosphorus and to decrease fixation are made. Phosphate fertilization is discussed.

## INTRODUCTION

Of the three major plant nutrients supplied to soils in the form of manure, it is phosphoric acid that is least accounted for in the crop. In a manurial experiment carried out at Peradeniya (1) where ammonium phosphate was applied to paddy at the rate of 96 lb. per acre, it was observed that the nitrogen added was fully recovered in the crop, but the quantity of phosphoric acid removed was only 20–25 per cent. This low return of phosphoric acid is due partly to the fact that a portion of what was applied was temporarily fixed in a form unavailable to plants. It should be noted here that the term fixation in agricultural usage is used to connote two contrasting ideas. When it refers to nitrogen it denotes a change from the unavailable (elemental) to the available state (nitrogenous compounds), while in the case of phosphoric acid it refers to a change from the available to the unavailable or difficultly available form. The phenomenon of phosphate fixation has been investigated by a number of workers. It is not proposed to review in detail the voluminous literature on the subject, but factors relevant to this investigation will be discussed under each section. Mention may, however, be made that the consensus of opinion is that fixation depends as summarised by Davis (2) on (*a*) the nature and content of the soluble and exchangeable basis. (*b*) the composition of the colloidal fraction, *i.e.*, its silica/sesquioxide molecular ratio, (*c*) the degree of saturation of the reactive components with phosphorus compounds, (*d*) the hydrogen-ion concentration of the soil, (*e*) the content and nature of the organic matter and (*f*) the physical condition which affect chemical equilibria including temperature, time and moisture content.

In Ceylon occurs a wide variety of soils, which vary greatly in texture, organic matter, reaction, and the nature of the clay. It was therefore considered desirable to study (1) the distribution of the different forms of phosphorus compounds in eleven of the soils belonging to the major soil groups of Ceylon and (2) the power of fixing added phosphates of these soils.

## SECTION (I)

### Distribution of the different Forms of Phosphorus in Soils

Phosphorus is known to exist in various forms in soils and Dean (3) was the first to attempt to fractionate them. Ghani (4) later improved on the method and divided the soil phosphorus into five fractions according to their chemical composition and availability to crops.

(1) Readily available—the three forms of calcium phosphates, soluble in $0 \cdot 002$ N. $H_2SO_4$ (pH $3 \cdot 0$).

(2) Moderately available—phosphates of aluminium and iron, the inorganic fraction soluble in $0 \cdot 25$ N. NaOH.

(3) Available on further decomposition only—organic phosphates such as phytin, lecithin, nucleic acid, &c.—the organic fraction soluble in 0.25N · NaOH.

(4) Probably unavailable—apatite, the fraction soluble in 2N. $H_2SO_4$.

(5) Definitely unavailable—the insoluble portion forming an integral part of the clay itself. The difference between the total phosphorus and the sum of the above four fractions.

Information was secured on the amount of each of these fractions present in the eleven soils, as the knowledge thus gained would throw light on the degree of availability of phosphoric acid to crops in these soils and also give an idea as to how best they should be treated, so as to enhance their nutrient status from the point of view of phosphoric acid. The characteristic features of the soils studied are given in Table I.

TABLE I

Important Soil Characteristics

| | Location | Depth of Sample | Reaction PH | Organic Matter Per cent. | Silica/ Sesquioxide (molecular) | Nature of Clay |
|---|---|---|---|---|---|---|
| 1. | Bopatalawa | 0–12″ | 4·39 | 9·76 | 0·92 | Laterite |
| 2. | ,, | 12–24″ | 4·39 | — | — | ,, |
| 3. | Massena | 0–12″ | 4·30 | 4·18 | 1·26 | ,, |
| 4. | ,, | 12–24″ | 4·32 | — | — | ,, |
| 5. | Ambepussa | 0–12″ | 4·96 | 1·78 | 1·40 | Lateritic |
| 6. | ,, | 12–24″ | 4·96 | — | — | ,, |
| 7. | Gampola | 0–9″ | 5·26 | 5·84 | 1·18 | ,, |
| 8. | Peradeniya | 0–9″ | 5·04 | 3·06 | 1·21 | ,, |
| 9. | Nalanda | 0–9″ | 6·99 | 2·07 | 1·69 | Non-lateritic |
| 10. | Bathalagoda | 0–9″ | 5·30 | 3·16 | 1·58 | ,, |
| 11. | Maha-Illupalama | 0–9″ | 6·83 | 2·32 | 1·61 | ,, |
| 12. | Matara | 0–9″ | 5·03 | 12·46 | 1·34 | Lateritic |
| 13. | Hingurakgoda | 0–9″ | 7·03 | 3·08 | 2·98 | Non-lateritic |
| 14. | ,, | 0–18″ | 7·18 | — | — | ,, |
| 15. | Jaffna | 0–9″ | 8·03 | 0·87 | 2·01 | ,, |

## EXPERIMENTAL

The method of extracting and determining the various fractions adopted by Ghani (4) was used in these studies with some modifications. In certain preliminary trials conducted, it was observed that Chamberland filter candle used by Ghani tended to absorb phosphates from solution in the process of filtration and that the slower the rate of filtration, the greater was the amount of absorption. The extraction was therefore carried out by treating 5 gm. soil, pretreated with 0·5N acetic acid to remove the exchangeable bases, with 200 cc. of ·25N sodium hydroxide for a period of six hours in a water bath at 70°C. In determining the readily available portion, 0·002N. sulphuric acid was used instead of 0·5N. acetic acid, as the former was the conventional reagent (Troug) used for extracting this form of phosphorus. Besides, the filtrate even with the organic soils, was quite clear for colorimetric determinations made in a Lovibond tintometer, which was not the case when acetic acid was used. Standard analytical methods were used in the other determinations. The results obtained are shown in Table II. To facilitate comparison the results are also worked out as percentages of the total phosphoric acid and shown in italics.

## TABLE II

### Fractions of Soil Phosphorus (Mgm $P_2O_5$ per 100 Gm Soil)

Figures in Italics refer to Percentages of the Total

| Location and Depth of Sample | Massena 0–12″ | Bopatalawa 02–12″ | Bopatalawa 12–24″ | Ambepussa 0–12″ | Matara 0–9″ | Peradeniya 0–9″ | Gampola 0–9″ | Batalagoda 0–9″ | Maha-Illupalama 0–9″ | Nalanda 0–9″ | Hingurakgoda 0–9″ | Jaffna 0–9″ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reaction pH | 4·30 | 4·39 | 4·39 | 4.96 | 5·03 | 5·04 | 5·26 | 5·30 | 6·83 | 6·99 | 7·05 | 8·03 |
| Readily available | 1·3 | 1·1 | 1·0 | 1.6 | 4·1 | 5·4 | 7·0 | 1·8 | 3·3 | 4·9 | 11·8 | 28·8 |
| | *·7* | *·4* | *·5* | *1.0* | *2·3* | *2·1* | *2·4* | *1·8* | *2·0* | *1·8* | *7·0* | *8·1* |
| Alkali Sol. Inorganic | 44·0 | 93·0 | 78·0 | 47.0 | 63·0 | 86·0 | 105 | 39·0 | 39·0 | 72·0 | 45·0 | 95 |
| | *25·0* | *36·9* | *39·2* | *27.9* | *34·8* | *33·3* | *35·9* | *38·2* | *23·1* | *26·3* | *26·9* | *26·7* |
| Alkali Sol. Organic | 68·0 | 112·0 | 60·0 | 48.0 | 73·0 | 111·0 | 120·0 | 36·0 | 50·0 | 60·0 | 42·0 | 80 |
| | *38·6* | *44·4* | *31·2* | *29.6* | *40·3* | *43·0* | *41·1* | *35·4* | *29·8* | *21·9* | *25·4* | *22·7* |
| Acid Sol. Inorganic | 21·0 | 13·0 | 18·0 | 23.0 | 17·0 | 22·0 | 27·0 | 14·0 | 38·0 | 72·0 | 42·0 | 98·0 |
| | *11·9* | *5·2* | *9·2* | *13.9* | *9·4* | *8·5* | *9·2* | *13·7* | *22·5* | *26·3* | *25·0* | *27·5* |
| Insoluble | 42·0 | 33·0 | 39·0 | 45.0 | 24·0 | 34·0 | 33·0 | 11·0 | 39·0 | 66·0 | 27·0 | 53·0 |
| | 23·9 | 13·1 | 19·9 | 27.3 | 13·2 | 13·2 | 11·3 | 10·8 | 23·1 | 24·1 | 16·1 | 14·8 |
| Total | 176·0 | 255·0 | 196·0 | 165.0 | 181·0 | 258·0 | 292·0 | 102·0 | 169·0 | 274·0 | 168·0 | 355·0 |

*Readily Available Phosphorus.*—This fraction is low except in the case of the Hingurakgoda and Jaffna soils, which are neutral and slightly alkaline respectively. Brown (5) points out that the greatest amount of available phosphoric acid is present at a pH of 7·9, as at this reaction the solubility of iron and aluminium is lowest and there is very little free calcium carbonate present. It will be observed that with a rise in pH the amount of readily available phosphoric acid also, as is to be expected, shows an increase.

*Alkali Soluble Inorganic Phosphorus.*—Though this fraction is second in magnitude in most of these soils, it is the most important one from the point of fixation, as added phosphates are likely to be converted principally into this form and the plants have to draw their requirements from this store. It varies in quantity in these soils, from 39·0 mgm percent in the Bathalagoda soil to 95 mgm. per cent. in the Jaffna soil. If the percentage figures are compared it will be observed that the highest percentage is present in the Bopatalawa soil and the lowest in the neutral Maha-Illupalama soil. In general there is a correlation between the pH of the soils and the amount of this fraction.

The average alkali soluble inorganic content, made up principally of iron and aluminium phosphates, is about 51 mgm. per 100 gm. soil, which works out to over 1,000 lb. per acre of soil to a depth of 6 inches. Ford (6) points out that ferric and aluminium phosphates are quite readily available to plants. Marais (7) also holds the view that mineral phosphates of aluminium and iron are valuable sources of phosphorus to plants. Hance (8) working under Hawaiian conditions asserts that plants like sugar cane utilize tri-calcium, ferric or aluminium phosphates. Troug (9) goes further when he reports that " nine out of ten plants gave better growth on aluminium phosphate than on calcium phosphate and that six made better growth on ferric phosphate than on calcium phosphate ". If the whole amount of this fraction exists as the normal phosphates of aluminium and iron, there then should be a sufficiency of this constituent to meet the requirements of most plants. In actual practice, however, when soluble phosphates are applied to most soils, they become unavailable to plants. It must therefore be conceded that the soluble phosphates, applied form compounds other than the normal phosphates of iron and aluminium and these the plants cannot utilize. Heck (10) states that the nature of the iron and aluminium phosphates formed would depend upon the state of hydration of their oxides. If the oxide of iron is fully hydrated, only then will the normal iron phosphate ($FePO_4$) be formed, but as tri-hydrated iron oxide is unstable, there is not much possibility of this reaction taking place. Ford (6) quotes Leith & Mead to show that goethite (limonite) $Fe_20_3 \cdot H_20$ and bauxite $Al_20{\cdot}_3$. $XH_20$ appear as products of laterization. He further demonstrates that the phosphatic compounds formed with goethite are as insoluble as dufrenite $Fe_20_3$. $H_3PO_4$ . Heck (10) is of opinion that compounds even more insoluble than dufrenite may be formed.

From the foregoing, it has to be inferred that iron and aluminium compounds of very low solubility are formed when phosphatic fertilizers are applied to soils, particularly of the lateritic and laterite types. As these compounds are also soluble in 0·25N. NaOH, the extent of the immediate availability of this fraction would depend on the proportions in which these two types of compounds are present.

*Alkali Soluble Organic Phosphorus.*—This constitutes the largest fraction in most of these soils. It varies in quantity much more widely than the inorganic portion, the lowest amount being found in the Ambepussa soil and the highest in the Gampola soil. A study of the percentage figures would indicate that an inverse relationship exists between the reaction of a soil and its content of alkali soluble organic phosphates, the higher amounts being found in the more acid soils. Organic matter also seems to exert its influence on the quantity of this fraction as indicated by the relatively high contents of the humic Bopatalawa and Matara soils and the paddy soil of Gampola. These may be the residual products of plant origin or synthesised products of bacterial action. Shorey (11) Wrenshall *et al.* (12) Yoshida (13) and Bottomley (14) have shown that organic phosphates exist in soil as lecithin in small quantities and as nucleic acid and phytin in relatively large amounts. Rogers and his associates, (15) claim to have established that corn and tomato absorb directly from nutrient solutions both phytin and lecithin, but many workers hold the view that these organic phosphates should first be mineralized to be taken up by plants. Pearson *et al.* (16) have demonstrated that the decomposition of phytin is slow, but that of nucleic acid is fast. Addition of lime leads to the rapid mineralization of phytin. The organic phosphates present in the local soils may therefore prove to be a valuable source of phosphorus to plants, if they are first mineralized by liming.

*Acid Soluble Phosphorus.*—It has been shown by Ghani and Aleem (17) that this fraction represents the apatite phosphates present. In the soils studied the highest amounts of this fraction are found in the soils of limestone origin from Jaffna and Nalanda, viz., 72 and 98 mgm. per cent. and the lowest in the acid soil of Bopatalawa where it is only 13·0 mgm. per cent. A comparison of the percentage figures would indicate that there is generally a rise in this fraction with an increase in the pH of the soils.

In the calcareous soils, the relatively high amount may be due to the formation of the very slightly soluble carbonate apatite, $Ca_3(PO_4)_2\ CaCO_3$.

*Insoluble Phosphorus.*—This fraction which is considered unavailable constitutes what remains in the soil after the alternate acid and alkali extractions. Here again the quantities are highest in the calcareous soils of Nalanda and Jaffna. Reaction seems to bear no relationship to the amounts present in the various soils.

## SECTION (II)

### Fixing Power of Soils for Phosphates

In this investigation the eleven soils referred to previously and the sub-soils of three of them were included. The method outlined by Hibbard (18) was adopted but instead of sodium phosphate, mono-calcium phosphate was used. The fixing capacity of a soil was reckoned to be, as defined by Hibbard, the milligrams of phosphoric acid required to be added to a kilogram of soil to give a concentration of 1 p.p.m. in the extract. Though phosphate fixation is considered to be a time reaction nevertheless over ninety per cent. of the fixation takes place in the first hour. The results obtained are given in Table III.

## TABLE III

### Phosphate Fixing Power of Soils

| Soil | Cwt./per acre as super | Mgm. $P_2O_5$ added | Mgm. $P_2O_5$ remaining in solution | Fixation | Fixing Power Mgm. $P_2O_5$ per 100 gm. soil |
|---|---|---|---|---|---|
| | | Per cent. | Per cent. | Per cent. | |
| Bopatalawa 0–12″ | 1680 | 50 | 0·012 | 99·9 | 690 |
| | 2016 | 60 | 0·060 | 99·9 | |
| | 2352 | 70 | 0·101 | 99·9 | |
| Bopatalawa 12–24″ | 2016 | 60 | 0·016 | 99·9 | 770 |
| | 2350 | 70 | 0·062 | 99·9 | |
| | 2688 | 80 | 0·120 | 99·8 | |
| Massena 0–12″ | 1344 | 40 | nil | 100 | 670 |
| | 2016 | 60 | 0·030 | 99·9 | |
| | 2352 | 70 | 0·139 | 99·8 | |
| Massena 12–24″ | 1680 | 50 | 0·039 | 99·9 | 750 |
| | 2352 | 70 | 0·076 | 99·8 | |
| | 2688 | 80 | 0·128 | 99·7 | |
| Ambepussa 0–12″ | 504 | 15 | 0·056 | 99·6 | 200 |
| | 672 | 20 | 0·100 | 99·5 | |
| | 1008 | 30 | 0·169 | 99·4 | |
| Ambepussa 12–24″ | 672 | 20 | 0·024 | 99·7 | 390 |
| | 1008 | 30 | 0·046 | 99·7 | |
| | 1344 | 40 | 0·104 | 99·6 | |
| Gampola 0–9″ | 672 | 20 | nil | 100 | 410 |
| | 1344 | 40 | 0·066 | 99·8 | |
| | 1312 | 45 | 0·206 | 99·5 | |
| Peradeniya 0–9″ | 336 | 10 | 0·028 | 99·4 | 210 |
| | 672 | 20 | 0·038 | 99·3 | |
| | 1008 | 30 | 0·114 | 98·8 | |
| Nalanda 0–9″ | 336 | 10 | 0·036 | 99·6 | 160 |
| | 504 | 15 | 0·099 | 99·3 | |
| | 672 | 20 | 0·108 | 99·0 | |
| Bathalagoda 0–9″ | 168 | 5 | nil | 100 | 95 |
| | 235 | 7 | 0·046 | 99·3 | |
| | 336 | 10 | 0·102 | 98·9 | |
| Maha-Illupalama 0–9″ | 168 | 5 | 0·038 | 99·2 | 71 |
| | 235 | 7 | 0·090 | 98·7 | |
| | 336 | 8 | 0·151 | 98·1 | |
| Matara 0–9″ | 67 | 2 | 0·016 | 99·0 | 53 |
| | 168 | 5 | 0·058 | 98·8 | |
| | 235 | 7 | 0·356 | 94·7 | |
| Hingurakgoda 0–9″ | 33 | 1 | 0·098 | 90·2 | 11 |
| | 67 | 2 | 0·192 | 90·3 | |
| Jaffna 0–9″ | 16 | 0·5 | 0·067 | 86·6 | 7 |
| | 33 | 1 | 0·15 | 85·0 | |

## RESULTS OF DISCUSSION

The data indicate that the soils vary greatly in their fixing power, the highest fixation being in the acid Bopatalawa soil and the lowest in the slightly alkaline Jaffna soil. Others showing comparatively high fixation are the Massena and Ambepussa soils. It will be observed that the sub-soils have higher fixation power than their corresponding surface soils. The high fixing soils besides being acid in reaction have clays of the laterite or lateritic type, while those showing low fixation are neutral in reaction and their clays are non-lateritic. It would therefore be seen that fixation is governed by the nature of the clay and/or the reaction of the soil. Beater (19) however points out that the effect of pH may not be looked upon as a dominant factor, as a large excess of active iron and aluminium are believed to overshadow its influence on the products of chemical action. Doughty (20) had established that natural or synthetic humus does not fix phosphorus. Fraps and Hamer (21) consider that in most cases fixation by organic matter is rather small. Since it is observed in this investigation that the surface soils have a lower fixation than the corresponding sub-soils and the acid, humic Matara soil also shows a comparatively low fixing power, our results would appear to confirm the view that organic matter plays only a minor role in fixation.

## GENERAL DISCUSSION

There is diversity of opinion among investigators as regards the mechanism of fixation. While some consider it a purely chemical action, others regard it to be of a physico-chemical nature. Whatever the mode of fixation may be, there is general agreement that compounds of iron and aluminium, particularly those in the laterite and lateritic soils react avidly with added phosphates making them unavailable. Romine and Metzger (22) had demonstrated that fixation was low, when the sesquioxides were extracted from soils by treating them with dilute acids. The works of Kelly and Medgley (23) and that of Fraps (24) bear this out. Bear and Toth hold the view that under conditions of low pH, soils with low silica/sesquioxide ratios fixed large amounts of phosphorus and that the reverse was true when the pH was high. The results reported herein indicate that the acid soils with low silica/sesquioxide ratios fix considerable amounts of added phosphates. Under the condition of this investigation, the main fixation products can only be the phosphates of iron and aluminium and the question of their availability has already been discussed.

The problem of the agriculturist is therefore to treat the soil by suitable means so as to release the phosphorus present in it and to minimise the fixation of added phosphates. The evidence in literature clearly indicates that pre-liming the soil reduces fixation very materially. It has also been shown that liming promotes the mineralization of the phytin present in the soil. There is however difference of opinion as to how far liming would be able to release phosphoric acid from the insoluble inorganic phosphates in soil. Holman (25) has given instances of highly laterised soils in New South Wales, in which no soluble phosphoric acid was released over a range of pH 3–8 and concluded that liming would not have the effect of making phosphates in them available. Cook (26) on the other hand had demonstrated that liming soils ranging in pH from 4·83 to 6·30 had increased the availability of soil phosphates significantly in seven out of ten soils and slightly in two. Bear and Toth (27) held the view that absorbed phosphates in soils may be colloid-bound or saloid bound. When colloid-bound, they could be displaced by hydroxyl, silicate or humate and when saloid bound by chloride, suplhate, citrate, tartrate, &c., Mattson (28) in dealing with the displacing power of anions placed the following in their descending order thus: humate, phosphates, silicate. According to Marais (7) the effect of lime on the basic aluminium phosphate is different to that on the corresponding iron compound. When the former hydrolyses, the aluminium hydroxide can combine with calcium to form the insoluble calcium aluminate releasing phosphoric acid but no such reaction takes place between calcium and iron hydroxide. Liming could therefore set free the phosphoric acid from aluminium phosphate but not from basic iron phosphates.

In view of the variation in the nature of the clays, reaction and fixing power of Ceylon soils, the importance of treating the different types differently will be readily understood. In the matter of phosphatic fertilization, the nature of the fertilizer, its amount, placement and time of application should receive consideration. From the results outlined herein, it is clear that rapid fixation of considerably high amounts of added phosphates takes place in the acid soils. It will therefore be seen that the application of soluble phosphatic fertilizers will not have any greater benefit on them than that of insoluble phospahtes. At Rothamstead it has been found that mineral phosphates are as good on acid soils as super. Vageler (29) advocates the application of larger amounts of cheap insoluble fertilizers in preference to smaller quantities of the costly soluble ones. Neutral or slightly alkaline soils on the other hand fix much less phosphorus than the acid soils. Soluble phosphates such as super should therefore be preferred to insoluble phosphates, the availability of which in these soils is very limited. According to Marais (7) Prainishnikov divided phosphatic fertilizers into two classes : one consisting of tricalcium phosphate, bone meal, phosphorite, &c., whose availability will be reduced by lime and the other made up of mono and di-calcium phosphates, Thomas slag, mono-potassium phosphate and iron and aluminium phosphates, &c., the availability of which is either unaffected or increased by lime.

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