STUDIES ON THE PHOSPHATE PROBLEM IN MALAYAN SOILS

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There is ample evidence, based on laboratory determinations judged in relation to the results of field experiments, to show that the amount of readily available phosphate in the majority of Malayan soils is inadequate for optimum growth of rubber trees (Hevea brasiliensis). Responses to treatment are often spectacular in young rubber areas where the concentration of added phosphorus per unit volume of soil in the root zone is relatively high, but with mature or nearly mature rubber trees responses to fertilisers are invariably small and often not detectable. The roots of the older trees occupy the whole of the surface horizon of soil and the effective volume of soil to be treated with fertiliser is consequently much greater. The amount of phosphate applied at this stage is usually less than 2 cwt per acre and never more than 3 cwt per acre per application. The concentration of added phosphate per unit volume of soil in the effective root space is now much less. When manuring at the time of planting, it is customary to mix 4 oz of phosphatic fertiliser with the surface soil in the planting hole. When this is done the concentration of added phosphorus per unit volume of soil in that space is approximately eight times as great as the concentration when a dressing of 3 cwt per acre is applied over the whole area. This suggests that marked growth responses are obtained when the concentration of added phosphate in the root zone is high, but that responses are relatively poor when the concentration is low. As long as the roots are confined to a small volume of soil, it is possible to saturate this volume at little cost. When roots spread over a large area the saturation of the total root space with phosphate becomes uneconomic.

When considering the reasons for the marked response to phosphate during the early stages of growth, and the lack of response later, there are several other factors to consider. The method of application, for instance, is important. The initial application in the planting hole, when the phosphate is mixed with the top six to eight inches of soil, is probably more effective than all subsequent applications on, or close to, the surface. Furthermore, there is evidence that phosphatic fertilisers have their greatest effect on some annual crops early in the growing stage and this may apply also to rubber trees. Nevertheless, the fact remains that only a small proportion of the phosphate added to soils is taken up by the crop at all stages of growth and it is of interest to consider the causes of this low efficiency of utilization.

It has already been reported (OWEN 1947) that Malayan soils have a high capacity for retaining phosphate in a form which is not easily available to plants. Although the degree of penetration of phosphorus into the soil varies within narrow limits, depending on soil type and on the form in which the fertiliser is applied, it has been shown that it seldom moves more than an inch or two from the point of application in local soils. Therefore little or none is lost by leaching and as long as the soil remains in position the phosphate stays too. It is generally accepted that the immobilization of phosphate in soil is due to reactions in which the phosphate is converted into relatively insoluble forms. This phenomenon is known as 'phosphate fixation'. Much attention has been devoted to this problem in all parts of the world and the more recent work on the subject has been reviewed by MIDGELY (1931) and by WILD (1950). The mechanism of phosphate fixation is not yet fully understood, but it is apparent that the phenomenon cannot be adequately explained on the basis of a single mechanism which is applicable to all soils.

To gain a better understanding of the problem, with particular reference to local soils, an attempt has been made to study the nature and distribution of the various forms of phosphate in these soils, before and after treatment with phosphatic fertilisers. It was thought that such a knowledge would throw some light on the causes of immobilization of the phosphate and the factors responsible for the low response of crops to phosphate applications.

EXPERIMENTAL

As material for the purpose of studying the distribution of native soil phosphorus in local soils, samples were obtained from control plots in 26 experimental areas on rubber estates, scattered throughout the country. These manuring experiments have been in progress for a number of years. Planting was done in the years 1937 to 1940 and growth measurements were recorded regularly up to the end of 1941 when the experiments were temporarily abandoned owing to the war. By the time the war ended and supervision of experiments was again possible, the rubber trees were mature and tapping commenced almost immediately. Postwar manuring started in 1947 and 1948, and fertiliser applications at two yearly intervals have been continued. Growth and yield records have been kept during the postwar period.

The early results of manuring in the majority of these experimental areas have been discussed by AKHURST and OWEN (1950). During the early stages of growth of the rubber plants, a marked response to treatment with phosphate was established in several experiments, all of which are sited on inland residual soils. These soils may be classified broadly into two groups: (*a*) the loams and clay loams, most of which are highly ferruginous, and (*b*) the sands and sandy loams. A beneficial effect due to postwar manuring with phosphate has been detected in only a few of these experiments so far, but since they all showed a marked response during the early stages of growth they are regarded as responsive areas. All experimental areas where no response to treatment with phosphate has been detected, either during the early stages of growth or after maturity, are those sited on coastal alluvial clays and peaty clay loams. These are referred to as the non-responsive soils.

For the purpose of studying the distribution of the various forms of phosphorus in soils after addition of phosphatic fertilisers a number of samples representing different soil types were selected from the responsive and non-responsive groups. Samples of each soil were treated as follows: (*1*) control - no treatment, (*2*) Christmas Island rock phosphate, (*3*) superphosphate, (*4*) monocalcium phosphate, and (*5*) sodium dihydrogen phosphate. Equivalent quantities of the phosphate compounds were thoroughly mixed with a known weight of soil. The amounts applied were equivalent to an application of 10 cwt per acre of Christmas Island rock phosphate. The samples were placed in stoppered bottles and kept moist during storage in the dark for one year. At the end of this period the contents of the different fractions were determined.

All the soils included in this investigation are acid, the pH varying between 3.8 and 5.6. The coastal alluvial soils are usually more acid than the inland residual soils.

METHODS

Methods used for fractionation of soil phosphorus involve several extractions of the same soil with different solvents. In preliminary work carried out, three methods in which acids and alkalis are used as extracting agents were compared. Procedures described by DEAN (1938), WRENSHALL and DYER (1939) and by WILLIAMS (1950) were followed. The methods are empirical and it is unlikely that a complete separation of the different phosphorus fractions is achieved by any of the procedures suggested so far, but the methods proposed are based on a study of the solubilities of the various forms of phosphorus likely to be present in soils, and they give a fair indication of the relative proportions of different fractions, with the possible exception of the organic phosphorus fraction. Judging from exploratory work in examining methods for the determination of the different forms of phosphorus in soils, it is considered that conditions for extraction and determination of the organic phosphorus fraction in particular need further study. However, Williams' method for the fractionation of soil phosphorus gave more consistent results than the others and this was adopted for subsequent work. A discussion of the distribution of the various forms of phosphorus in soils before and after treatment with phosphate is based on the results obtained by this method.

The procedure described by Williams is a modification of the method proposed by GHANI (1943) in which the acid soluble phosphate is first extracted by 2.5% acetic acid containing 1% 8-hydroxyquinoline. The alkali soluble inorganic and organic phosphorus fractions are then extracted by 0.1 N sodium hydroxide. The total soil phosphorus was determined by digestion with hydrochloric acid.

On the basis of a study of the solubilities of a number of phosphatic minerals and prepared phosphate compounds in the extracting solutions specified, WILLIAMS (1950) concludes that the soil phosphorus fractions separated by successive extraction with acid and alkali, according to the procedure described, are as follows:

1. *Acid soluble fraction*—Water soluble phosphates; phosphates of calcium, magnesium and manganese; hydroxy- and carbonate-apatite and, to some extent, chloro- and fluo-apatites.
2. *Alkali soluble fraction*—
   a. Inorganic phosphates which include adsorbed phosphate, basic aluminium and iron phosphates, and titanium phosphate.
   b. Organic phosphorus.
3. *Fraction insoluble in both the acid and alkali extractants*—Mainly chloro- and fluo-apatites, crystal lattice phosphorus and some resistant phosphate minerals.

Most of the phosphorus in the first fraction is in a form which is readily available to plants. At least part of the alkali soluble fraction can also be utilized. Recognition of the importance of anion exchange reactions in soils leads one to the conclusion that adsorbed phosphate must play a part in the phosphorus nutrition of plants. The organic phosphorus fraction too is probably important; at least it forms a reserve supply from which available forms of phosphorus will be gradually released. The third fraction, representing a portion of the total phosphorus occurring in a form which is not extractable either by dilute acids or alkali, is probably completely inert.

NATIVE PHOSPHORUS IN SOILS FROM EXPERIMENTAL AREAS

The mean values for the different phosphorus fractions in the three soil groups are shown in TABLE I.

TABLE I: NATIVE PHOSPHORUS IN SOILS FROM EXPERIMENTAL AREAS
Mean values in p.p.m. P_2O_5

Soil group	*Inorganic*		*Organic*	*Inert*	*Total*
	Acid sol	*Alkali sol*			
Inland soils—loams, clay loams	4	23	61	128	216
Inland soils—sands, sandy loams	16	12	86	53	167
Coastal alluvial clays and clay loams	29	96	240	211	576

The content of calcium phosphates and other forms of phosphorus soluble in dilute acids is consistently low in the first group of responsive soils, the values ranging from 0 to 10 p.p.m. The inert phosphorus fraction is the highest individual fraction in these loams and clay loams, and about 28% of the total phosphorus occurs in the organic form.

In sandy soils, the proportion of acid soluble to alkali soluble phosphates is more variable. The content of alkali soluble inorganic phosphorus is usually lower in these soils than in others, ranging from 0 to 24 p.p.m. but values for the more readily available acid soluble fraction show a bigger variation. The organic phosphorus is the highest individual fraction amounting, on average, to about 52% of the total phosphorus.

The coastal alluvial soils, in which available forms of phosphorus are usually adequate for normal growth of rubber, contain appreciably more of all forms of phosphate than the other two groups. It is perhaps significant that values for the acid soluble fraction are consistently higher in these non-responsive soils than in others. In only one of the experimental areas in the non-responsive group does the value fall below 15 p.p.m. Compared with this fraction, the content of alkali soluble inorganic phosphate is invariably greater and the values fall over a wider range (12 to 280 p.p.m.). The organic form of phosphate is again the largest individual fraction amounting, on average, to 42% of the total phosphorus content.

The relevant information regarding the distribution of extractable inorganic and organic phosphate fractions in soils which respond, and those which do not respond, to treatment with phosphate may be summarised as follows:

Fraction	*Responsive soils*	*Non-responsive soils*
Acid soluble	Usually less than 10 p.p.m. Sandy soils may contain more but values above 15 p.p.m. are not common.	Usually greater than 15 p.p.m.
Alkali soluble (inorganic)	Values are variable within the range 0 to 46 p.p.m.	Usually greater than 25 p.p.m. and may be as high as 280 p.p.m.
Alkali soluble (organic)	Usually less than 100 p.p.m.	Usually greater than 100 p.p.m.

These results do not allow for a reliable assessment of the relative contribution of the different fractions to the phosphorus nutrition of rubber plants. However, it is generally accepted that the forms of phosphorus extracted by dilute acids are more readily available than other forms. The difference between responsive and non-responsive soils could be explained on the basis of the relative contents of the readily available acid soluble fraction, but the assumption that this is the only fraction which determines whether a soil will or will not respond to treatment with phosphate may not be valid. General observations on the performance of rubber trees in the experimental areas, when considered in the light of results discussed herein, lead to the conclusion that at least part of the alkali soluble fraction, both inorganic and organic forms, does contribute to the phosphate nutrition of plants in these soils. It is difficult to avoid the conclusion that the non-responsive soils react differently from the others when treated with phosphatic fertilisers, not only because they contain more of the acid soluble phosphates but because they contain relatively greater amounts of both acid soluble and alkali soluble fractions which include both inorganic and organic forms of phosphate.

THE ADDED PHOSPHATE IN FERTILISED SOILS

The fertilisers were mixed with the soil samples at a rate supplying 227 parts of P_2O_5 per million parts of soil (equivalent to an application of 10 cwt Christmas Island rock phosphate per acre). The results showing the distribution of the various phosphorus fractions in these soils one year after treatment indicate that, under the conditions in which this experiment was carried out, little or none of the fertiliser phosphorus added was converted into organic forms. That proportion of the added phosphate which was recovered by successive extraction with dilute acid and alkali was present in inorganic forms. The percentage recovery varies according to soil type, but recovery values for soils within each of the three groups into which the soils under consideration are broadly classified are of the same order of magnitude. Recovery was least in the ferruginous loams and clay loams while all, or nearly all, of the phosphate added to the coastal alluvial clays was recovered in forms which were soluble either in dilute acid or in alkali. A summary of the results is shown in TABLE II.

TABLE II: RECOVERY OF ADDED PHOSPHATE IN FERTILISED SOILS
Mean values expressed as percentage of amount added

Soil group	*Inorganic*		*Total recovery*
	Acid sol	*Alkali sol*	
Inland soils—loams; clay loams	1.3	61.7	63.0
Inland soils—sands; sandy loams	35.2	38.4	73.6
Coastal alluvial clays and clay loams	25.8	74.9	100.6

The percentage recovery of added phosphate was least in the loams and clay loams, averaging only 63%. It is to be noted that the amount recovered by extraction with dilute acetic acid is negligible. The inference is that nearly all the fertiliser phosphate added to these ferruginous, residual soils is converted into forms which are not readily available to plants, and more than a third is converted into forms which probably are completely inert.

In the sands and sandy loams as much as 35% of the added phosphate remains in the acid soluble form and about the same amount is converted into a form which is less readily available but probably not completely useless for the phosphate nutrition of plants. About one quarter of the amount added is converted into relatively inert forms.

All the phosphate added to the coastal alluvial soils was recovered by successive extraction with dilute acid and alkali. About a quarter of the amount added remains in the acid soluble form and the remainder is converted into a form which can be extracted by alkali. Probably most of the latter occurs as adsorbed phosphate in these heavy alluvial clays, a form which can be utilised by plants though probably less readily than the acid soluble forms.

In regard to the behaviour of the various forms of phosphatic fertilisers used in this investigation, the results reveal no important differences between one form and another; greatest recovery in all soils is obtained when sodium di-hydrogen phosphate is used. The differences are small but consistent, and there is a suggestion that sodium phosphate is less readily converted into insoluble forms than the other phosphate compounds used. This suggestion is supported by the evidence reported previously (OWEN 1947) indicating that the phosphate of sodium applied on the surface of local soils penetrates more deeply than other forms of phosphate.

In soils treated with the soluble phosphate compounds, the relative proportion of acid soluble and alkali soluble fractions recovered one year later is fairly constant for each group of soils. In all three groups the alkali soluble fraction is consistently greater than the acid soluble fraction. Rock phosphate on the other hand behaves differently in the different soil types. When added to the ferruginous loams and clay loams none was recovered by extraction with dilute acetic acid. In the coastal alluvial clays about a third of the amount recovered occurs in the acid soluble form, but in the sands and sandy loams the ratio of acid soluble to alkali soluble fraction is reversed, two thirds of the phosphate added still remaining in the acid soluble form. The distribution of the various phosphorus fractions in soils treated with the different phosphatic fertilisers is shown in TABLE III.

TABLE III: RECOVERY OF ADDED PHOSPHATE IN SOILS TREATED WITH DIFFERENT PHOSPHATIC FERTILISERS

Mean values expressed as percentage of total recovery

Soil group	*Rock phosphate*		*Super-phosphate*		$CaH_4(PO_4)_2$ H_2O		NaH_2PO_4 $2H_2O$	
	Acid sol	*Alk sol*	*Acid sol*	*Alk sol*	*Acid sol*	*Alk sol*	*Acid sol*	*Alk sol*
Inland soils—loams; clay loams	0	100.0	2.6	97.4	1.8	98.2	3.0	97.0
Inland soils—sands; sandy loams	67.8	32.2	40.0	60.0	44.4	55.6	40.9	60.1
Coastal alluvial clays and clay loams	32.9	67.1	32.8	67.2	26.6	73.4	17.9	82.1

The results indicate that the fate of both soluble and insoluble phosphatic fertilisers is similar when applied to the ferruginous loams and clay loams. All or nearly all of the phosphate added, whether as rock phosphate or as water soluble phosphate compounds, is fixed by adsorption or by precipitation as the phosphates of iron and aluminium. In other soils, however, an appreciable proportion of the phosphorus added remains in an acid soluble form. The inference is that fixation by adsorption and by precipitation as insoluble compounds is less rapid and less complete in the sandy soils and in the alluvial clays.

It will be observed that the major proportion of the added phosphate recovered usually occurs in the alkali soluble form. The only exceptions are sandy soils treated with rock phosphate. The probable explanation for this anomaly is that rock phosphate dissolved rather more slowly in these sandy soils and, under the conditions in which the experiment was carried out much of it remained in its original form.

DISCUSSION

On the basis of morphological characteristics, phosphate status and response to treatment with phosphate fertilisers Malayan soils may be classified broadly into three main groups: (*a*) the heavier residual soils, whose texture ranges from loams to clay loams, (*b*) the lighter sands and sandy loams which include residual soils derived from sand-stones as well as soils derived from inland alluvial deposits and (*c*) the coastal alluvial clays and clay loams.

Members of the first group of soils considered in this study have certain characteristics in common: low silica sequioxide ratio of the clay fraction, low base exchange capacity, low content of soluble constituents and a high capacity for removing phosphate from solution. These soils are classified as latosols. The sands and sandy loams include lateritic and podsolic types depending on whether they are derived from sandstones or from recent sandy alluvial deposits. They have many characteristics in common with the first group and rubber trees growing in soils of both groups respond to treatment with phosphate fertilisers. The coastal alluvial soils are non-lateritic; they have a greater base exchange capacity and a higher content of soluble constituents. Rubber trees growing in these soils do not respond to treatment with phosphate.

A study of the distribution of the various forms in which the native soil phosphorus occurs in local soils shows that the contents of the individual fractions vary according to soil type. In the latosols, the content of acid soluble forms of phosphate is exceptionally low; the values are much lower than those in Australian soils discussed by WILLIAMS (1950). This acid soluble fraction consisting of forms of phosphate generally regarded as the most readily available to plants, is invariably less in the latosols and in the sandy soils than in the coastal alluvial clays and clay loams. But so are the contents of both organic and inorganic forms of the alkali soluble fraction. In other words, the concentration of all forms of phosphate dissolved by successive extraction with dilute acid and alkali is consistently less in the responsive than in the non-responsive soils.

When phosphate is added to soils only a proportion of this remains in a form which can be utilised by plants. Some is converted into forms which cannot be recovered by extraction with dilute acid or alkali, and it may be assumed that this fraction is relatively inert. It is of interest to note that the conversion into relatively inert forms is appreciable when phosphate is added to the latosols but little or none is converted into this form when added to the coastal alluvial soils.

Also of practical interest is the relative distribution of the less inert forms of added phosphate, *i.e.* the fractions which can be recovered by extraction with dilute acid and alkali. All components of these fractions cannot necessarily be utilized by plants but at least the acid soluble fraction is readily available. About a quarter of the phosphate added to the coastal alluvial soils remains in this readily available form and the remainder is converted into alkali soluble forms, a part of which can also be made use of by the plants. When phosphate is added to the sands and sandy loams, about a quarter of it is converted into inert forms, but the remainder is more or less equally divided between the acid soluble and alkali soluble fractions. It would appear, therefore, that an appreciable proportion of the phosphate added to either the lighter sandy soils or to the coastal alluvial clays remains in a readily available form. It follows that if these soils contain insufficient phosphate for the growth of any particular crop, a response to phosphate manuring in the ordinary way can be expected. Coastal alluvial soils usually contain sufficient phosphorus in a readily available form for the nutrition of rubber trees and the need for phosphate manuring of rubber areas on these soils seldom arises, but other crops may require additional phosphate. Sandy soils, whether they are residual or alluvial soils, usually require additions of phosphate as well as other nutrients for the growth of rubber trees. The evidence suggests that there is no urgent need to adopt any special measures for preventing the immobilization of added phosphate when applying fertilizers to these sandy soils or to the heavy coastal alluvial soils if and when the occasion arises. When these soils are deficient in phosphate a response to treatment with phosphatic fertilizers can be expected because an appreciable proportion of the phosphorus added remains in a readily available form.

Let us consider the other group of soils—the loams and clay loams in inland areas derived from underlying parent rocks. These residual soils are important in so far as they cover much larger areas than the other two groups mentioned; the more extensive rubber growing areas in Malaya are on soils which fall within this group. They are almost always deficient in phosphate and it has been shown that values for available phosphate, as determined by standard chemical methods, invariably fall below ten parts per million. When phosphate is added to these soils only a small fraction remains in the acid soluble form (usually less than

2% of the amount added), about 60% is converted into alkali soluble forms and the remainder into inert forms.

When considering the effect of manuring these soils with phosphate we have to bear in mind that more than half the phosphate added is converted into alkali soluble inorganic forms. This fraction, which includes adsorbed phosphate and the phosphates of iron and aluminium, is the only fraction likely to be of any importance for the phosphate nutrition of plants in the soils under consideration; the supply of the more readily available acid soluble forms is negligible in comparison. How much of the alkali soluble phosphate fraction can be utilized it is not possible to say, but it is generally accepted that adsorbed phosphate is a source from which phosphorus can be absorbed by the plant. But these particular soils have a low silica/sesquioxide ratio and it is reasonable to assume that basic aluminium and iron phosphates form the major components of the alkali soluble phosphate fraction in these soils. It would seem that the bulk of the phosphate added to this important group of inland soils is converted into forms which have a low degree of availability for plant use. It is with reference to these soils in particular that the need for considering ways and means for reducing phosphate fixation and increasing the efficiency of applied phosphate fertilizers is most urgent. The fact that nearly all the phosphate added to these soils is converted into forms which, at best, are only slowly available, probably explains why responses to phosphate manuring in most mature rubber areas have been disappointingly small and are only detected after several applications over a period of years.

Examination of the results showing the distribution of native phosphorus in the soils under study shows that a relatively large proportion of the total phosphorus is present in the organic form. Although the data presented offer no evidence as to the importance of the organic phosphorus fraction, the fact that it is the largest individual fraction in most soils examined is probably not without significance. Several workers have reported evidence that soil organic phosphorus is utilized by plants to as great an extent as is inorganic soil phosphorus, and possibly even greater. Field observations in rubber plantations clearly indicate that rubber trees derive much of their sustenance directly from decomposing organic matter on the surface of the soil. The development of a mass of rootlets in and around the decomposing organic debris on the ground suggests that the nutrients released through decomposition are absorbed before they come in contact with the soil. Furthermore, recent work by STRUTHERS and SIELING (1950) has shown that organic matter may have another important function in releasing soil phosphorus. They show that fixation of phosphate can be greatly reduced by some of the organic acids which are produced when organic matter decomposes in the soil. Considering all these observations together, it does seem that soil organic matter may play a very important part in the phosphate nutrition of plants. It is possible that the best device to improve the efficiency of utilization of fertilizer phosphate may be to convert it into organic phosphorus, or apply it in the zone where there is the greatest concentration of organic matter. The possibility that it may be better to apply phosphates to the ground cover in the spaces between rubber tree rows, rather than to the soil in the cleared spaces along tree rows, merits consideration. It may be that the solution to the problem of phosphate nutrition of rubber trees lies in maintaining a dense ground cover by regular applications of the phosphate directly to that cover. This is an aspect of the phosphate manuring problem which merits careful study.

SUMMARY

A study of the nature and distribution of the various forms of phosphate in soils, before and after treatment with phosphatic fertilizers, has been made. This was an attempt to gain some information on the causes of immobilization of the phosphate in local soils and to consider the factors responsible for the low response of mature rubber trees to phosphate applications in soils known to be very deficient in phosphate.

Most of the Malayan inland soils contain negligible proportions of the more readily available forms of phosphorus, such as the water soluble phosphate and calcium phosphates. The major portion of the total soil phosphorus occurs in a form which is not extractable either by dilute acids or alkali, a form which may be regarded as relatively inert. Most of the remainder is present as alkali soluble inorganic and organic phosphorus. It would seem that plants growing in these particular soils must draw their supply of phosphate mainly from this fraction which includes forms of phosphorus generally regarded as having a low degree of availability. Young rubber plants growing in these soils invariably show a marked response to treatment with phosphate during the early stages of growth.

In soils which contain adequate amounts of phosphate for normal growth of rubber trees, a large proportion of the total phosphorus is present as acid soluble and alkali soluble fractions. In other words, these soils contain appreciable amounts of the more readily available acid soluble forms as well as adsorbed and organic phosphorus, which may be assumed to contribute, directly or indirectly, to the phosphorus nutrition of plants.

When phosphates are added to soils they are converted into different forms, some of which are readily available to plants, others which are available only with difficulty and some which are relatively inert. The relative distribution of the various forms is determined by soil type, and probably by the concentration of the phosphate added, but it would seem that the type of fertiliser applied to these acid soils has but little effect on the final distribution of the various forms of phosphorus. There is a suggestion, however, that the rate of conversion from easily soluble to less soluble forms may be governed by the type of fertilizer used.

There are indications that, in sandy soils and in the coastal alluvial clays and clay loams, an appreciable proportion of the phosphate added remains in a form which can be utilized by plants. In the more widely spread ferruginous inland soils (latosols), however, a large proportion of the added phosphate is rapidly converted into inert forms, and most of the remainder is probably available only with difficulty. It is with reference to these soils that the need for considering ways of increasing the efficiency of phosphate manuring is most urgent.

Attention is drawn to the fact that a relatively large proportion of the total phosphorus is present in the organic form in most of the soils examined. It is concluded that the importance of soil organic matter in relation to the phosphate nutrition of crops in local soils is a subjejct which merits closer study in further investigations on the phosphate problem.

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