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Food

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All living things need food of some kind, and all food comes from green plants which are able to utilize solar energy, inorganic compounds, and salts as their sources of food. Life, therefore, depends on the green plants as the primary source of food.

The study of plant nutrition and ways to promote plant production is consequently a vital part of man's endeavour and it has been pursued for centuries by thoughtful people. In so doing it has been assumed that once the need for a particular nutrient element was known it would also be possible to apply it in the right form, at the right time, and in the right way. This was, and still is, true but it may not be true for all time and for all plant food elements. Thus, while the sources of the macronutrient elements, nitrogen and potassium, from a practical standpoint are infinitely large the source of phosphorus is not. How large the source, i.e. deposits of mineral phosphate, is and how long it will last is difficult to estimate. The various estimates made by competent people vary from 30 to 300 years. This may be of little or no consequence, the main point is that the end of phosphorus supply is within sight. Furthermore, phosphate mineral is the only mineral extracted from Mother Earth for which there is no substitute. It is also a fact that if phosphate minerals are no longer available, agricultural land on this planet will not be able to sustain the present world population, let alone a greatly increased one. One does not need to be an alarmist to appreciate that. The recent 300 % price increase of useful mineral phosphate is a sure sign of things to come.

The obvious thing to do in this situation is firstly to apply the knowledge already obtained from the research on phosphorus in soil and plants. This knowledge is very great indeed, as it ought to be as more research has been done on this single element than on all other plant food elements put together. This knowledge mainly concerns the way phosphorus is retained by soil, the mechanisms involved in uptake of phosphorus by plant roots, and the phosphorus requirement of various crops grown on different soils. It is useful in a situation where it is a question of applying phosphatic fertilizers that are available in abundance and at a comparatively low price. It is less useful or downright useless when phosphatic fertilizers are in short supply or are not available at all as may be the case in a foreseen future. In this situation other measures than use of imported phosphatic fertilizers must be taken. The only other measures which can be taken are mobilization of the phosphorus reserves in the soil itself and recycling of phosphorus in animal and human waste.

With regard to the phosphorus reserves in soil they are very large when taken on the basis of the total phosphorus content in soil and compared with the phosphorus requirement of crops.

Thus, the magnitude of this reserve is of the average order of 2000 kg P/ha in the plough layer as compared with an annual removal by a crop of 10 to 20 kg P/ha. There should therefore be no need to apply phosphorus provided ways and means could be found to mobilize this reserve. This was already pointed out 150 years ago by Daubeny who advocated the use of crop rotations with fallows during which the depleted pool of plant available phosphorus (and potassium) in the soil could be replenished by mobilization of 'dormant' phosphorus. It is worth noting that these ideas were put forward by Daubeny (at the Bakerian Lecture of the Royal Society, London in 1838) before the advent of factory-produced phosphatic fertilizers in the middle of the 19th century and the discovery of vast deposits of high-quality mineral phosphate in North Africa in the 1870s. These developments did not only overtake Daubeny's ideas but as a result of the booming fertilizer industry the total phosphorus content of many cultivated soils in industrialized countries have more than doubled since the introduction of chemical phosphatic fertilizers. The reason for this is the well-known fact that crops only remove some 10 % of the applied phosphorus and the equally well-known fact that most soils have a great capacity to retain phosphate even when it is added in water-soluble form. Of all the fertilizer phosphorus which has been applied in the course of the last 100 years, 90 % is therefore still present in the soil. The soil reserve – or soil bank as some prefer to call it – is thus even greater to-day than when Daubeny delivered his lecture to the Royal Society. The most obvious result of this development is that significant responses to application of phosphatic fertilizers are now very difficult to come by in industrialized countries. Consequently many prominent advisers to the farming community have in course of time recommended a reduction of the phosphate consumption. However, this advice fell on stony ground. For example, one of my famous predecessors, the late Professor Bondorff, advocated in 1940 an almost halt to the use of phosphatic fertilizers in Danish agriculture. The opposite happened. Denmark's consumption of phosphatic fertilizers (mainly singly superphosphate) has increased three-fold since 1940 and it was still increasing by a rate of 3 % per annum until the recent dramatic price increase of the raw material. Whether it will continue to increase remains to be seen.

Whatever way it goes, Denmark, like most other industrialized countries, is in a maintenance situation as far as phosphorus is concerned. That is, in most soils it suffices to maintain the present phosphate status of the soil. This of course poses the question: how much phosphorus must be added to maintain the phosphate status of the soil? The first approximative answer to this question is: the amount removed by the crops. This answer is, however, only correct if the phosphate status of soil is not changed by processes other than crop removal. Such other processes can be leaching, erosion, and immobilization in the soil. Of these processes the first is unimportant in most soils and the second is restricted to soils exposed to erosion, while the third is the great unknown and deserves closer examination.

Immobilization of phosphorus in the sense of removal of phosphate from the aqueous phase to the solid phase in soil has been subject to much research. However immobilization, in the sense of removal of phosphate from the pool of available phosphate in soil to forms of phosphate which are not available to plants, is far less studied and – it must be admitted – is far less suited for short-term studies as this process proceeds very slowly. It is in some cases so slow that many people have preferred to assume that it does not happen at all. If that assumption is correct we, i.e. the industrialized countries, are in the happy situation that we can, if the need arises, draw on the huge reserve of phosphate accumulated in our soil. If that is so we could grow crops for many centuries without encountering phosphate deficiency. Nevertheless, though some soils may show residual effects of phosphate for a century or more, the cultivation of other soils may very shortly be made uneconomic by phosphate deficiency, if application of phosphatic fertilizers ceases. There is, however,

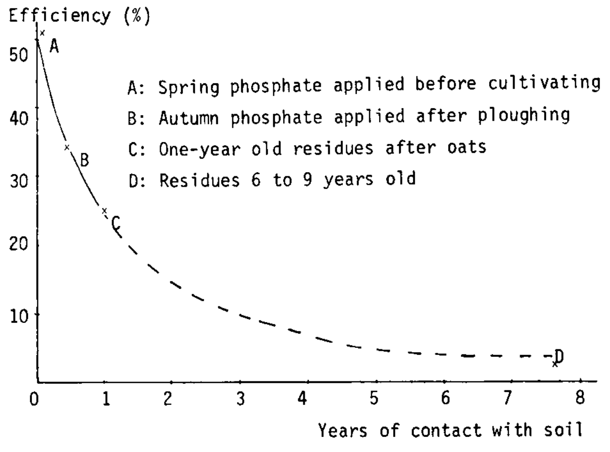

Fig. 1. Efficiencies to root crops of phosphate residues and dressings applied at different times, compared with fresh phosphate applied just before ridging (Williams & Reith, 1971. Residual value of applied nutrients. *Tech Bull. Min. Agric. Fd Fish.* 20: 16–33. HMSO, London.)

no general truth concerning the persistence of residual phosphate effects in soil. The only general truth there is, is that its availability to crops will decline with time and it will do that in the exponential fashion shown in Fig. 1. Because the decline (or decay) is exponential, no finite lifetime can be ascribed for the decay of phosphate availability in soil. In this situation the half-life is the appropriate measure of the decay. In the limited work on this kind of phosphate immobilization in soil, half-lives between 1 to 6 years were determined in mineral soils (Larsen et al., 1965; *J. Sci.* 16: 141–148). More such data are urgently needed not only in order to predict the time it will take to reach the catastrophic situation of crop failure due to phosphate deficiency, but also to enable a determination of what the maintenance rate of phosphate application should be in order to allow for immobilization and removal of phosphorus by cropping.

It is obvious that conventional field experiments are useless when there is no response to the applied fertilizer as the case is when phosphate is applied to soil containing large amounts of residual phosphate. The only way the required information can be obtained is by methods which measure the pool of available phosphate in soil independently of crop response. The most suitable of such methods so far applied is the isotopic dilution method which has the advantage of being able to measure the pool without addition of any chemicals which may bring about mobilization or immobilization of the phosphate in the soil. It may also be used in soils with growing plants. In this case mobilization of hitherto non-available phosphate may occur but it will be brought about by the plants and not by chemicals which are alien to soil.

Although the tool to follow the decay of phosphate availability in soil exists little concerted effort to unravel the soil factors which govern this process has been made. The situation with regard to phosphate immobilization in soil is nevertheless much better than with regard to the rate of mobilization on which hardly any research has been done. The phenomenon of phosphate mobilization as such is well recognized from long-term experiments on phosphate exhaustion, but in these experiments it has mainly been a question of mobilization of the native phosphate already present in soil. The very large amounts of residual phosphate in soil has not yet been subject to long-term experiments on representative soils although starts have been made to establish such field experiments in some places.

The problem with such field experiments is not their design which may be very simple, but the time scale. Thus several decades may elapse before a degree of depletion which results in yield depressions has been reached. Information may be obtained in shorter time if the following simple balance-sheet is applied: phosphorus removed by cropping minus decrease in the labile phosphorus pool in the soil.

If the difference is positive, a mobilization of non-labile phosphorus must have taken place or, if only the plough layer is sampled, the crops may have drawn phosphorus from deeper layers. The latter complication may be overcome by taking soil samples from these layers.

But even if such a phosphorus balance is made it will take several years before significant results accrue. Furthermore the number of soil types which can be covered by such a series of field experiments is, for practical reasons, very limited. The number may, however, be increased by conducting phosphorus depletion experiments in small pots. Several experiments of this type have, with success, been used to measure the release of nonlabile potassium from soil minerals. Nevertheless this pot experimental technique is less suited for measurement of the phosphorus release from soil as the test crop, grass repeatedly cut during the growing period, soon fails due to phosphorus deficiency. There is, therefore, a need for short-cut laboratory methods for the purpose of obtaining parameters of phosphate release from soil. The choice of methods is here very limited because only agents which do not alter the state of phosphorus in soils are applicable. In fact it is limited to distilled water or water saturated with CO_2. Daubeny used the latter extractant for determination of what he called 'active' phosphorus in soil. The capacity of these two agents to remove phosphorus from soil is, however, too small to be of any use in determining the release of non-labile phosphate in soil. One way to increase this capacity is to introduce an anion exchange resin charged with chloride ions into the system of soil and water. The resin which, apart from its ability to exchange anions, is inert, will, when applied in sufficient quantities, provide a very large sink for the phosphate ions (and other anions) and will bring about the following series of reactions:

$$P_{\text{non-labile}} \xrightarrow{\text{very slow}} P_{\text{labile}} \xrightarrow{\text{fast}} P_{\text{solution}} \xrightarrow{\text{very fast}} P_{\text{resin}}$$

By changing the resin at short intervals, e.g. 24 hours, the capacity to adsorp phosphate can be kept up. This may be done by using resin beads placed in a perforated vessel emerged in a soil suspension. Therefore the limitation caused by the slow phosphate diffusion in static soil is minimized.

By applying this experimental technique it should be possible to make the release of non-labile soil phosphorus the rate-limiting step once the bulk of labile phosphorus has been removed from the soil.

The advantage of this method over depletion by cropping is that, unlike plants, resin will not suffer from phosphate deficiency. Furthermore, the complication of slow diffusion is avoided. There might be other complications, such as a build up of calcium chloride or aluminium chloride in the solution phase. These latter may be overcome simply by changing the solution from time to time.

Though such laboratory methods based on above principles may not be quick and easy by laboratory standards, they hold out a hope of assessing the release of the vast amount of phosphorus accumulated in soil. A knowledge of the ease by which non-labile phosphorus may be released will be helpful in periods of phosphate shortage, in that it will form a basis for deciding where phosphate can be saved and where it must be applied and thereby postpone the evil day when crop production is seriously limited by phosphate deficiency. Nevertheless, the time will come when phosphatic fertilizers are no longer available. Methods which will enhance the release of phosphate present in abundance in soil, in a form which the plants can use, must then be found. How this is to be done in such a way that full yields can be obtained is a much more difficult question to answer. That it can be done on an experimental scale has already been demonstrated by E. G. Williams who extracted soil with 2.5 % acetic acid and 0.007 *N* sulphuric acid, respectively, and found a greatly increased uptake of phosphorus by plants grown after restoration of cation content and pH of the soils (*J. Soil Sci.* 2 (1951): 110–117). There is, however, a very long way from such experiments to a practical application. It is also more than doubtful if the principle of acidification followed by neutralization can be applied on a field scale. It is more likely that a conserted effort of plant breeders, microbiologists and soil chemists will be needed in order to make it possible for plants to utilize the vast reserve of phosphate in soil.

There may or there may not be time for the necessary research work in this field. Either way, a solution to the phosphate problem will have to be found if starvation on a hitherto unknown scale is to be avoided some time in the not too distant future. True, more urgent problems may occupy our minds and time, but in the long term the well-being of mankind rests on a solution to the phosphate problem.