

Utilisation of Phosphatic Fertilisers by Plants, after their Absorption into the Soil

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THE absorptive power of the soil, with respect to phosphates, is often considered harmful; it is said to retain in practically unavailable forms the greater part of the soluble phosphates applied, and to do this not only in certain special types of soil, such as laterites, but in most soils. It is supposed that crops do not generally recover more than about 20 per cent. of phosphatic fertilizers. This opinion is based on 3 sets of facts.

1. The soluble phosphates incorporated in the soil become in time, more and more difficult to extract by chemical reagents.

2. It has sometimes been found that the efficiency of phosphatic fertilizers decreases rapidly with the time of contact with the soil, in the absence of any vegetation (Scarseth & Tidmore)¹.

3. If the quantities of phosphorus are compared in crops which have, and which have not been manured with phosphate, the difference is found to be small in relation to the dose applied, about 10 per cent., often less. The residual effect on a second crop is even smaller, and on a third almost nil, so that the sum of successive effects and even the summation for an infinite series of crops is far from total utilisation.

This view, as applied to most soils, is open to a serious objection. If plants could recover altogether only 1/5 of the soluble phosphates applied, it would be necessary, to maintain fertility, to supply the soil with 5 times the amount of phosphates consumed by the crop. Now, it seems likely that, in many soils, the fertility can be maintained *at its existing level* by merely restoring the amounts removed. This indeed was the opinion of the agronomists of the last century; according to them if the phosphate reserves of the soil were maintained by addition of soluble phosphates, this reserve remained capable of releasing to a particular crop a constant quantity of phosphoric acid under given conditions. This implies that the total application of phosphates would be recoverable by a sufficiently prolonged succession of crops. It is this contradiction that we have tried to resolve.

I. Conservation of the efficiency of phosphatic fertilizers during 16 years in a loamy soil

Gericke² has recently established, in various soils, that the efficiency of phosphatic fertilizers is found to be scarcely reduced after 18 months ageing in bare land. But he agrees that it should continue to decrease slowly over a very long period. However, we have at Versailles an experimental field which has been under observation for 16 years. It was established by

Demolon and Burgevin in 1928. It comprises plots receiving annually a fixed dose of simple fertilizer, particularly superphosphate or basic slag. The soil is always kept free of vegetation, but receives normal cultivation.

In this soil, an average slightly acid loam (pH 6.3 in 1928, dropping to 5.8 in 1942), the phosphates incorporated have undergone profound modifications. If a graph is drawn, with abscissa to show the years (or what amounts to the same thing the total quantity of P_2O_5 used since the beginning) and with ordinates to show the totals of P_2O_5 extractable by mild reagents (particularly dilute acetic acid), it is noticed that these totals increase less and less quickly during the first years, but that it augments each year after by a constant quantity. The diagram obtained begins with a convex curve continuing as a straight line rising slightly. The presence of this slight rise shows that the fixation of the phosphates tends towards an equilibrium at which extractability is not nil. It needs about 5 years for each annual addition to complete its evolution.

Now, in this experimental field, the application of fertilizers ceased in 1941, (14 applications). We were then in 1944, dealing with a soil containing phosphatic fertilizer which on the average had aged 10 years, the last application being not far from the end of its evolution. We can therefore consider the efficiency of these fertilizers corresponds more or less to the "end-point" of the ageing.

In 1944, we took earth from these plots and used it as phosphatic fertilizer in pot-cultures of barley. We compared its fertilising action with that of the same quantity of the same fertilizer applied immediately before sowing.

Phosphatic manuring : 0,200 g. P_2O_5 for 10 Kg. of a brown limestone soil
containing 12 per cent. of $CaCO_3$.
Weight of dry matter harvested.

	Without Phosphatic fertilizers	Phosphatic fertilizers in the natural state applied immediately before sowing	Phosphatic fertilizers after 10 years in slightly acid soil
Superphosphate ..	100	186	184
Basic Slag ..	100	140	177

The aged superphosphate exercised more or less the same fertilizing action as the recent Superphosphate. The aged slag was noticeably more effective than the fresh slag.

These results which confirm over a long period those of Gericke, do not agree with the doctrine of progressive inactivation of phosphates by irreversible fixation in the soil. If such an inactivation took place, it could only occur in the short interval between the application of the fertilizer and the rooting of plants sown immediately after the manuring.

II. Selective absorption of phosphatic fertilizers by plants and the conservation of soil reserves

Up to the present, the part played by the phosphatic fertilizers in the nutrition of plants has been assessed by the indirect method already mentioned, which consists of comparing the quantities of phosphorus contained in a harvest with and without fertilizer. This method rests on the assumption that plants borrow from the soil reserves the same quantity of phosphorus in the two cases. But appearances would be the same, if the plants were selectively taking the fertilizer and leaving the reserves.

In experiments on maize cultures on solutions in pots divided into 2 compartments (with division of the root system), one series of plants received a solution rich in phosphates (36 or 18 mg. P_2O_5 per litre) in one of the compartments, and a solution poor in phosphates in the other compartment (1.8 mg. P_2O_5 per litre). Another series received the same weak

solution in both compartments. We have observed that the weak solution in association with the rich solution supplied less phosphate to the maize than when associated with another weak solution.

Concentration of the weak solution after 24 hours (initial concentration = 1.8 mg. P_2O_5 per litre)	
Weak solution associated with weak solution	Weak solution associated with rich (18 mg.) solution
0.17	0.70

The excess take-up of one part of the roots reduced the intake of the others. The same experiment was repeated in earth in pots, and in the field. Superphosphate was mixed with a small proportion of soil (1/16 in the case of the pots), the mixture distributed in cylinders of metal mesh, scattered in the soil which had no phosphate fertilizer.

After cultivation, the total loss of phosphorus from the earth in the cylinders was determined by analysis. In pots, barley took about 60 per cent. of the phosphoric acid added in the cylinders, and 50 per cent. in the field.

Moreover, if a complete balance-sheet of phosphorus in these experiments is drawn up, the quantity actually taken from the fundamental reserves of the soil can be calculated, since the total quantity consumed by the plants is known (by analysis of the crops) and the quantity actually taken from the fertilizers. It is thus established that the soil reserves supply in the presence of fertilizers less phosphate to crops than in the absence of fertilizers. This action of sparing reserves in the soil reached 60 per cent. in pots, 40 per cent. in the field, representing 19.6 lb. P_2O_5 per acre.

It is thus explained why an addition of phosphatic fertilizers as a rule only increases the consumption of phosphates by crops to a moderate degree.

These facts also explain why the efficiency of phosphate fertilizers disappears rapidly on cultivated land, without denying its conservation on bare land.

III. Adsorption of phosphates at the surface of clays, especially in combination with alkaline-earth cations³

One fact remains surprising, the conservation of the efficiency of phosphatic fertilizers in bare soil, in spite of the progressive reduction of their solubility in certain chemical reagents. That is why we have sought to find whether the adsorption of phosphates in the soil does not show some feature capable of explaining this anomaly.

A. Demolon and Barbier⁴ have established that the calcium of clays is directly concerned in the retention of phosphates, independently of all precipitation of calcium phosphates in the true sense of the term. The following facts confirm the existence of adsorption compounds comprising clay, calcium ions, phosphoric ions, quite distinct from true calcium phosphates, and specify the conditions of their formation.

1. Different clays (a sub-soil loam, a Kaolinite and a montmorillonite) retain in the form of a calcium salt much more phosphates than in the form of a potassium salt, even when the initial concentration of phosphates in the solution is markedly lower than the point of precipitation of calcium phosphates under the conditions of the experiment.

2. If the concentration in phosphates is varied, characteristic curves of typical adsorption phenomena are obtained; the quantity of phosphates absorbed becomes proportionally lower as the concentration in the solvent is higher, both in Ca clays and in K clays.

3. Between about pH 6 and 7, alkalisation by the addition of lime impedes the retention of phosphates by calcium clays, i.e., favours the maintenance of phosphates in solution.

4. Equilibria are rapidly established; the supplementary quantity of phosphates retained by the Ca clays practically attains a maximum after $\frac{1}{4}$ hr's. agitation of aqueous suspensions. The subsequent progress of the absorption of phosphates does not depend on the nature of the exchangeable cation.

5. In the absence of flocculating salt, the Ca clays only adsorb a small quantity of phosphates; the adsorption increases very rapidly with addition of traces of a flocculating salt (Ca chloride or sulphate) up to a maximum, corresponding to complete flocculation of the clay (about 2N/100) as if the phosphoric ions could be retained only between two surfaces cemented by flocculation.

To define the quantitative importance of these calcium linked adsorption compounds in the soil as described above (which contains phosphatic fertilizers, 10 years old), we set out from the hypothesis that dilute acids, which easily detach exchangeable calcium, should separate in a short time the phosphoric ions thus retained. Obviously dilute acids (acetic or sulphuric) at pH 3.0 in the cold extract an important fraction of the applied phosphates, and that in an almost explosive fashion, as one can judge by percolating a thin layer of earth under reduced pressure so that the acid passes through the soil in a few seconds.

By 3 or 4 short acid extractions one can recover about $\frac{1}{3}$ of the fertilizers applied. Another $\frac{1}{3}$ separates instantaneously if one takes up the residue in very dilute alkali (2N/1000). The phenomena of reversion or "fixation" of the phosphates in the soil studied appears to consist essentially in a limited evolution of forms easily extractible by dilute acids into forms easily extractible by dilute alkalis* (probably in consequence of a slow adsorption by ferric hydroxides which finely coat the surface of mineral particles.) Now the passage from the 1st to the 2nd forms does not appear to inhibit to any marked extent the phosphorus intake of plants in the soil studied, for basic slag, of which the phosphoric acid remained much more easily extractible by dilute acids than that of superphosphate, does not show, after 10 years, an efficiency superior to that of superphosphate. This may explain why a loss of solubility in acid reagents does not necessarily involve a loss of efficiency.

Conclusion—One must not exaggerate the disadvantages of the absorptive power of soils in regard to phosphates. The present study does not resolve the question of whether a fraction of the soluble phosphates incorporated in the soil can form there compounds completely and definitely inert. But it does show that this fraction, if it is not absent, is comparatively small, at least in the soils, which do not cause an inactivation of phosphates on ageing.

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*See on this subject the article by A. Dean. An attempted fractionation of the soil phosphorus, *J. Agr. Sci.* 28, 234-246 (1938).

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