RESIDUAL PHOSPHORUS RESPONSE

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Introduction

Recent interest about the residual effects of applied phosphorus (P) on crop growth, prompted a complete review of the subject by Sadler and Stewart (1974), which included not only direct experimental data, but also related information about the fundamental processes in soil-plant relationships and in soil-fertilizer interactions. The purpose of this paper is to highlight a few of the major aspects of the above mentioned review.

Results of Residual Phosphorus Fertility Studies

Traditionally, the effects of applied P on crop growth have been assessed only during the year in which the P was applied. Results of such experiments have shown that only between 5 and 25% of the fertilizer P was used by a crop, or at least recovered in the harvested above-ground portions in the year in which the fertilizer was applied. Until recently, it was generally assumed that this low crop utilization efficiency was due mainly to the rapid "fixation" of the applied P by soil constituents in forms that were of very low availability to plants. Thus, it was also assumed that the applied P remaining in the soil after the first crop was of negligible economic importance to succeeding crops.

Evidence from long-term fertility studies indicates that these assumptions are incorrect. Studies have been conducted by Campbell (1965) and co-workers in the United States and by Read *et al*. (1973) in the Canadian prairies to trace the effects of single large applications of superphosphate, applied at rates of anywhere between 30 and 400 kg P/ha, on crop yield and soil

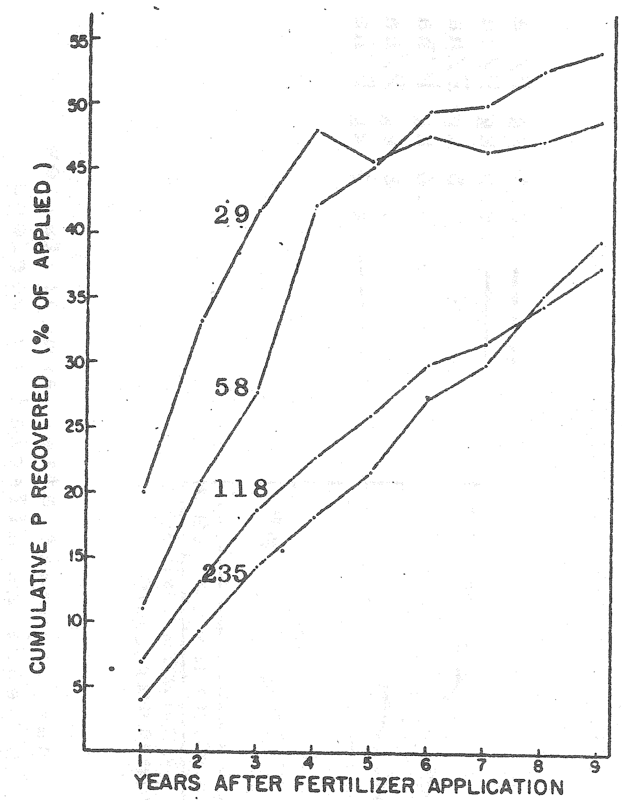

Fig. 1 Cumulative P recovery by crops through 9 years as affected by rates of initial P fertilizer application. Amounts are kg P/ha (Campbell, 1965).

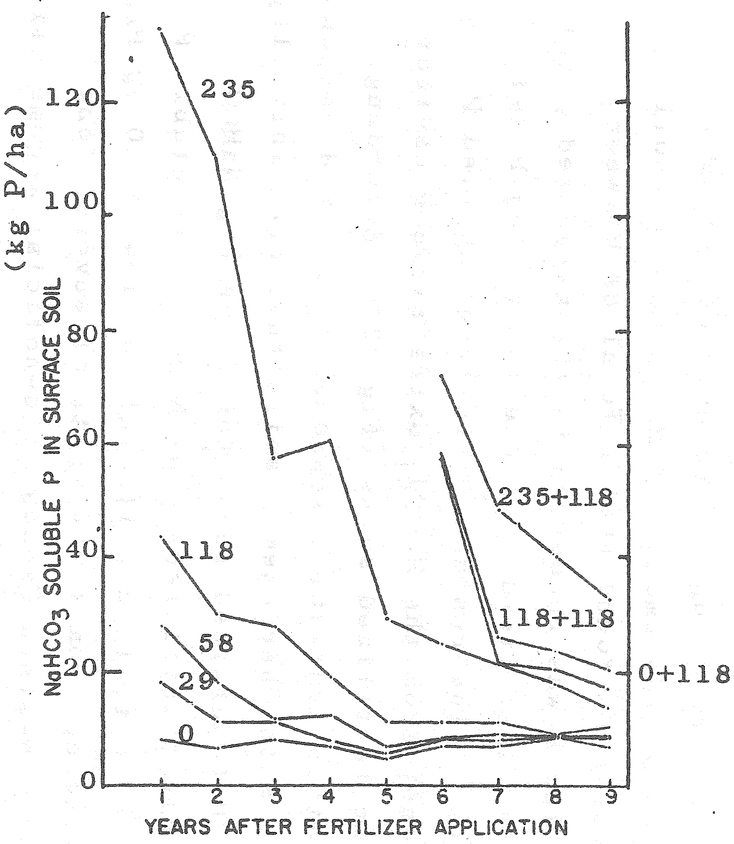

Fig. 2 Annually determined amounts of $NaHCO_3$-soluble soil P in surface 8 inches as affected by fertilizer applications the first and sixth years of the experiment. Amounts are kg P/ha (Campbell, 1965).

P fertility. It was found that residual response of crops to the applied P lasted for periods up to and even exceeding 10 years (Fig. 1) depending on the amount of P applied, on soil conditions, etc. It was also found that a total of between 35 and 87% of the applied P was recovered in the harvested plant material by the time residual yield response to applied P had ceased to be measurable. The residual effects of applied P were also clearly evident from the $NaHCO_3$ extractable P content of the top 15 cm of the fertilized soils (Fig. 2). According to the limited information available, residual crop yield response to fertilizer P, applied to Chernozemic soils that were initially very low in available P (contained less than 10 μg P/g $NaHCO_3$ extractable P) may persist until levels of $NaHCO_3$ extractable P in the top 15 cm of the fertilized soils fall as low as 10 μg P/g.

There is also evidence from the results of several long-term fertility trials in Western Canada of beneficial accumulative effects on soil P fertility and crop yield of fertilizer P applied on a regular basis at smaller, more usual rates of application. For instance, Spratt and McCurdy (1966) applied P every third year to a wheat-wheat-fallow rotation on an initially very P deficient calcareous Chernozemic soil (Fig. 3).

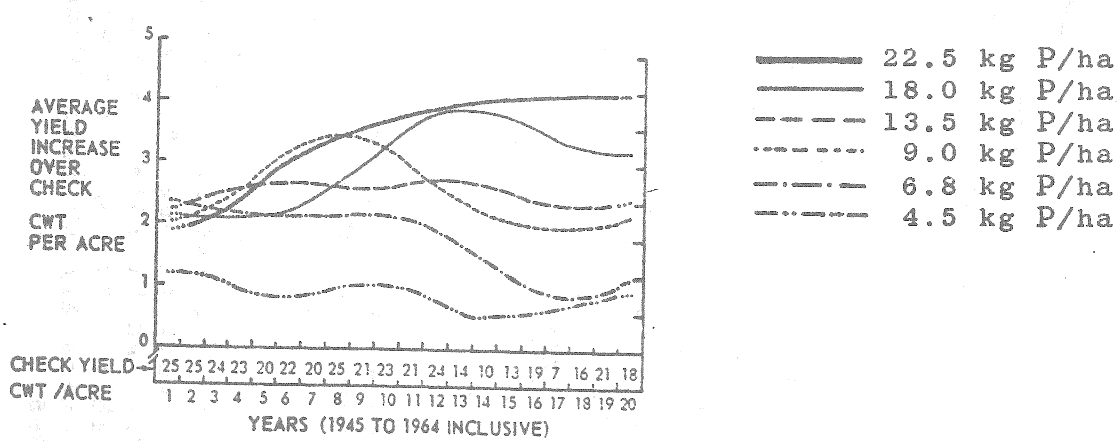

Fig. 3 Yield increases of wheat after summer fallow over a period of 20 years as affected by various rates of fertilization with monoammonium phosphate. The curves represent 3-year sliding averages (Spratt and McCurdy, 1966).

They found that crop yields as well as crop yield response to P applied at rates of 18 kg P/ha or more at each data, increased over a 20-year period. However at rates of less than 9 kg P/ha, crop yields declined with time after the first few years, suggesting that the soil became "nutritionally exhausted". None the less, at the end of the experiment, levels of plant available P were higher in all of the P fertilized soils than in the non-fertilized control soils.

To summarize the present data from residual P studies: The evidence strongly suggests that a considerable portion of the fertilizer P, not used by a crop immediately following application of the fertilizer, remains in a form that is available to succeeding crops, provided that the rooting distribution of the crops and critical growth factors such as levels of available nitrogen and water in the soil permit it to be utilized. Indeed, the results of most field studies show that the residual yield response of perennial crops such as grasses to fertilizer P is likely to be of greater economic importance than the yield response during the year of application. With regard to annual crop production, Read _et al_. (1973) in their most recent paper, conclude that infrequent single large applications of P may be as effective as smaller annual applications of P placed with the seed.

This latter statement represents a complete reversal from previous ideas on this subject and will need careful evaluation. Unfortunately, the data derived from residual P studies conducted to date is insufficient to permit one to make anything more than very general statements or to understand what, in some instances, appear to be conflicting results. There are several reasons for this state of affairs.

Firstly, few experiments have been designed to examine residual effects of applied P. Thus, few reports contain sufficient basic crop or soil data.

Secondly, differences exist between studies in the type of information recorded and in the methods used to obtain this information.

Thirdly, most residual P studies have depended on empirical or trial and error approaches.

It is apparent from present day knowledge of the fundamental processes in soil-plant relationships that several different soil factors directly affect the supply of phosphorus to plant roots. Thus, further progress in understanding and evaluating the residual effects of applied P on crop growth, will require a much better characterization of soil P status than that provided by empirical, single valued indices such as the $NaHCO_3$ extractable P index.

Soil Factors Affecting Phosphorus Availability to Plants

The immediate source of P for plants is the very small amount that is in soil solution. Since the rate of P uptake by plant roots has been found to be proportional to the concentration of P in laboratory nutrient culture systems, it follows that a measure of the P concentration in soil solution, or P intensity, should be an adequate measure of the P supplying power of that soil. This is not so in practice. If one considers the replenishment of solution P from solid inorganic sources as P is taken up by roots of growing plants, then there are two additional main factors which will affect the rate of P uptake.

Firstly, there is the capacity factor which describes the ability of a soil to maintain its solution P concentration against P uptake by plant roots. It defines the relationship between the quantity of available P and solution P concentration for a given soil.

Secondly, there is the rate of movement of P in solution from soil to root surface. This is determined by the soil P diffusion coefficient.

Studies have shown that both factors are positively related to the clay content of a soil. The soil diffusion coefficient is also positively related to volumetric soil moisture content and to root size. Olsen and co-workers in the United States

(Olsen and Watanabe, 1970) developed a diffusion equation in which the amount of P (Q) removed by a crop was related to a measure of the capacity factor (b) and to the soil P diffusion coefficient (D_p) in the following simplified manner:

$$Q \propto \sqrt{b\ D_p}$$

This equation predicts that the rate of P uptake by roots will be 1/3 as much from a sandy as from a clay soil at equal P concentrations; a fact that was confirmed by experimental data. It is apparent therefore, that in order to achieve equal P supplying power to a crop in soils of different texture, the P concentration must be inversely proportional to the clay content of a soil. In Figure 4, P concentration is expressed as the potential term $p(H_2PO_4 + HPO_4)$.

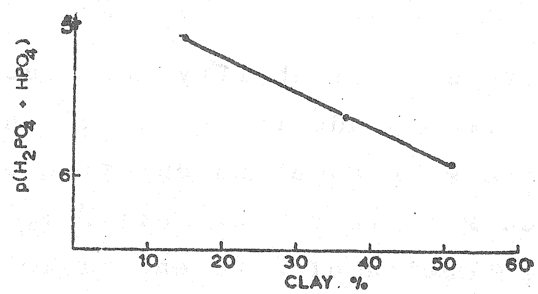

Fig. 4. Relation between the potentials, $p(H_2PO_4{+}HPO_4)$, at equal P-supplying power and the clay contents of soils. (Olsen and Watanabe, 1970)

It has long been recognized that organic forms of soil P are not directly available to plants. However, they may undergo mineralization to orthophosphate and thereby contribute to the supply of P to plant roots. Recent evidence obtained by Halm (1972) shows that mineralization of organic and microbial P in a Sceptre clay may provide a major part of the plant P requirements, particularly for perennial crops such as grasses. He found that whereas a wheat crop on this soil responded to applied P, the native grassland did not. This was attributed in large measure to the ability of the perennial crop to make use of the large quantity of organic P mineralized at the time of the spring thaw before the wheat crop had germinated.

Further evidence of the importance of organic P mineralization to the P supply of perennial crops has been provided by Cole et al. (1974). These workers tried to develop a computer simulation model of the flow of P through two grassland-soil ecosystems and found that in both systems, it was impossible to have the model simulate measured P values unless organic P mineralization and microbial P fluctuations were considered.

There is only limited and rather conflicting evidence at present that fertilizer P has any real effect on soil organic P. However, this aspect should not be neglected in future studies.

The Forms of Inorganic Phosphorus Fertilizer Reaction Products In Soils

Information on the nature, availability and stability of inorganic P fertilizer reaction products in soils can be of assistance in predicting the magnitude and duration of the residual effects of applied P on levels of soil P fertility. This is illustrated by the results of a recent field residual P study by Sadler (1973).

In non-fertilized, very P deficient Chernozemic soils, it was found that P concentration in soil solution was controlled by the solubility of impure hydroxyapatite. Two months after the field application of monoammonium phosphate to these same soils, the P concentration now corresponded to the solubility of dicalcium phosphate dihydrate. This represents a hundred to a thousand fold increase in P concentration. As expected the initial product dicalcium phosphate underwent conversion with time to another meta-stable form octocalcium phosphate, with a resultant decline in P availability. None the less, P concentration in these soils, three years after P application, remained at a level which was more than adequate for plant growth: Inorganic P fractionation data for these soils showed that less than 10% of the applied P underwent conversion to the ultimate product hydroxyapatite during this time.

One may conclude from the results of this work that a large part of fertilizer P applied to Chernozemic soils will remain in a readily available form such as dicalcium or octocalcium phosphate until removed by crop uptake.

These findings agree with the residual P crop and soil data of Read et al. (1973). They showed that after the initial short period of reaction between soil and fertilizer P, further reduction in the availability of the applied P with time was due almost entirely to crop uptake.

Summary

Obviously, it would not be possible for researchers conducting residual P investigations in the field to attempt the type of detailed investigations undertaken for instance by Olsen and co-workers on P transfer processes, by Halm on P cycling or by Sadler on P reaction products. However, unless the knowledge obtained in these aforementioned studies is utilized and serious attempts made by all researchers to collect soil and plant data that fit into the sort of computer simulation model that Cole et al. developed, it is very possible that the same confusion will exist with residual P responses in ten years as is the present case.

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