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SOLUTION-PHOSPHATE CONCENTRATION AND MAINTENANCE-P APPLICATIONS IN A HILL SOIL

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Abstract

Capital and maintenance dressings of phosphate to hill pastures are considered as part of an overall curvilinear response to phosphate under conditions of phosphate accretion with the degree of response in the maintenance period dependant on the level of prior phosphate input. The response to phosphate in plant growth rate is governed by the concentration of phosphate in solution in the soil. The concentration of phosphate in solutions in equilibrium with hill soils of different histories of phosphate application has been measured and the results expressed in terms of a hyperbolic convergence derived from the concept of capital and maintenance dressings. A reduced response, in solution phosphate concentration, to phosphate application was observed in soils which had received lower prior applications and in soils from which current phosphate inputs had been withheld.

It follows, that any reduction in phosphate input will cause, not only a lowered solution phosphate concentration, but also a lowering of the increase in phosphate concentration per incremental phosphate addition. This points to a possible lowering of the efficiency in the utilisation of applied phosphate when the input of phosphate to hill pastures is reduced.

Keywords: solution phosphate, phosphate fertility, capital inputs, maintenance inputs, hill soils.

INTRODUCTION

Phosphate is applied to pasture soils to provide a phosphate supply sufficient to produce little, or no limitation to plant growth. The amount that needs to be applied to achieve this determines the efficiency of the system, This is recognised in the concept of "capital" and "maintenance" dressings of phosphate. Initially, large amounts of phosphate must be added to provide the desired plant growth. This is often uneconomic in terms of cost of input and value of current return, but it is done in the knowledge that, subsequently, the required inputs will be substantially less, For this reason, the initial inputs are called "capital" dressings for they, in effect, purchase the more efficient subsequent system. The difference between these two systems is merely a difference in their efficiencies of utilisation of applied phosphate.

Since efficiency can be defined in many ways, the subject of efficiency of phosphate utilisation is a controversial one (Parfitt & Lee 1979, Karlovsky 1979). One efficiency index which has gained some acceptance relates the input of phosphate to the amount absorbed by the plant plus that retained by the soil in extractable form (Karlovsky 1981). Such an index gives high efficiency whatever the phosphate input and no change in efficiency with change in input, but in order to obtain stable efficiency indices over a range of phosphate inputs, it is necessary to include the phosphate retained by the soil as part of the phosphate output. This implies a capital component still operative as part of the maintenance dressings. Of prime concern to the agriculturalist is the simple efficiency in terms of increased plant growth from applied phosphate, and it is in rerms of this efficiency that the response to capital and maintenance phosphate applications will now be considered. In this context, two well founded principles will

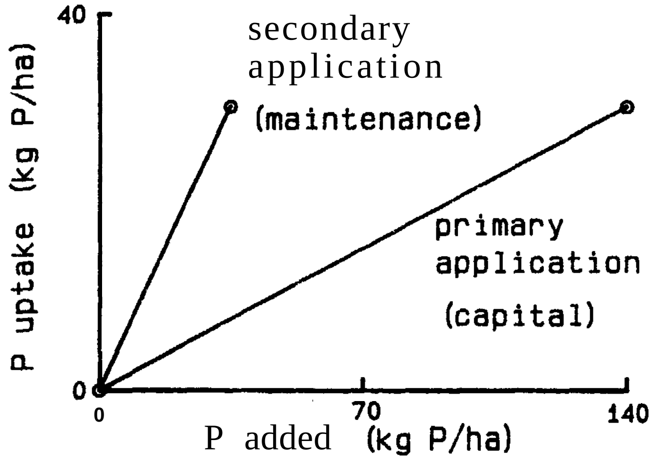

Figure 1: Response slopes of herbage P uptake to single phosphate application. (Redrawn from Fox (7980)).

be accepted: First that under conditions of phosphate limitation, the rate of plant growth is controlled by the concentration of phosphate in the solution at the plant root surface (Wild 1964), and secondly, that the capital and maintenance response phenomena are not independent of one another.

Figure 1 illustrates the two response systems, where the efficiencies are given by the slopes of the response lines. The two systems are not independant for the slope of the maintenance line is predetermined by the quantity of phosphate previously applied. The two systems may be considered to be merely crude linear approximations of an overall curve similar to that relating the response of

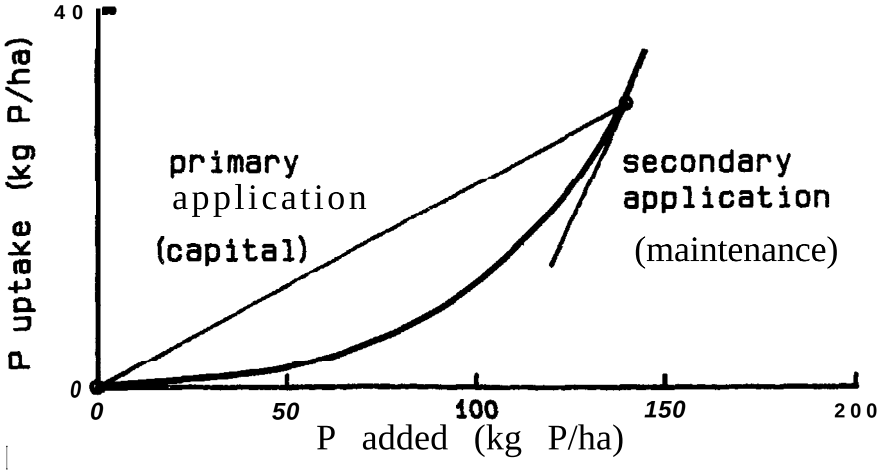

Figure 2: Response slopes of primary and secondary applications from Fig. 1, expressed as approximations of an overall response curve.

phosphate concentration to phosphate input (Fig. 2). Depending on how far along the "capital" line the pasture soil has progressed, the steeper will be the "maintenance" line. The steeper the line, the more efficient is the utilisation of added phosphate. Resolution of part of a curve into a straight line is a useful ploy to obtain a slope or efficiency index at that point. However, it is not valid to extrapolate along that line for this assumes linearity beyond the tangential point. Thus, it is erroneous to assume that the efficiency of the system will remain constant under conditions of change in phosphate input. A more systematic analysis of this curve must be evolved.

The soil may be considered to absorb, or immobilise a quantity (Q) of the added phosphate. Once this has been satisfied, then all subsequently added phosphate is available for solution, i.e. there will be a 1 : 1 relationship between the solution P ([P]) and added P (PA). The overall relationship may then be expressed as the hyperbolic convergence on this 1 :1 line;

$$[P] = b + PA - Q(1 - (1/(1 + aPA)))$$

where b accounts for the intercept when PA = 0 and a is a constant (1/mol) related to the mean bonding strength of the soil for phosphate. The slope of this curve,

$$d[P]/dPA = 1 - aQ/(1 + aPA)^2,$$

which reaches a maximum of 1 convergent on the line $[P] = PA - Q$, gives the index of efficiency in terms of the ratio of solution phosphate to P applied.

Data from a previous study (Mouat 1983) of solution phosphate concentration in phosphate retentive soils fitted this hyperbolic relationsip, and it was decided to see how changes in phosphate input to a hill soil may affect the parameters of this curve. In particular, does change in input alter the slope of the curve for any given subsequent input, for this slope expresses the efficiency of phosphate application in increasing the solution phosphate concentration.

METHODS AND RESULTS

Soils with different histories of P input were sampled from plots of different fertiliser treatment of the grazing trial at the Grasslands Division Ballantrae Research Area (Lambert *et al.* 1982). The phosphate treatments were (D.A. Clark *pers. comm.*):

High (HH)	= 630 kg superphosphate/ha/yr for 7 years.
High discontinued (HO)	= 630 kg superphosphate/ha/yr for 6 years, with no subsequent input in 7th year.
Low (LL)	= 125 kg superphosphate/ha/yr for 7 years,
Low discontinued (LO)	= 125 kg superphosphate/ha/yr for 6 years, with no subsequent input in 7th year.

The "Low" phosphate treatments were considered to be an economically sub-optimal rate of application (Lambert *et al.* 1982). Plots were sampled three months after the superphosphate treatments of the seventh year. Solution phosphate associated with different P additions to soils from these plots were measured in diffusion cells (Mouat 1983). The diffusion cell separates the solution from the soil while allowing free movement of phosphate between the two. Sub-samples from composites from each of the above treatments were placed in diffusion half-cells with 1.5 ml solution of varying P content and left to equilibrate for two weeks at 25°C. The phosphate which diffused in three days into a coupled half cell containing 3 ml of 1mM $CaCl_2$ was measured after the method of Murphy & Riley (1962).

The hyperbolae gave highly significant fits to the data in all four soils (Fig. 3). It can be seen that applied phosphate is much more readily released in solution form in the soils which had greater phosphate inputs in the past. The response slopes were significantly steeper in the soils from the High P input plots, indicating a greater efficiency in terms of soluble P obtained per unit of P applied. Associated with this has been a reduction in the total quantity (Q) of phosphate which may be immobilised by the soil.

Regression analysis also found that the discontinuing of phosphate application for one year caused a significant overall reduction of 16% in this efficiency.

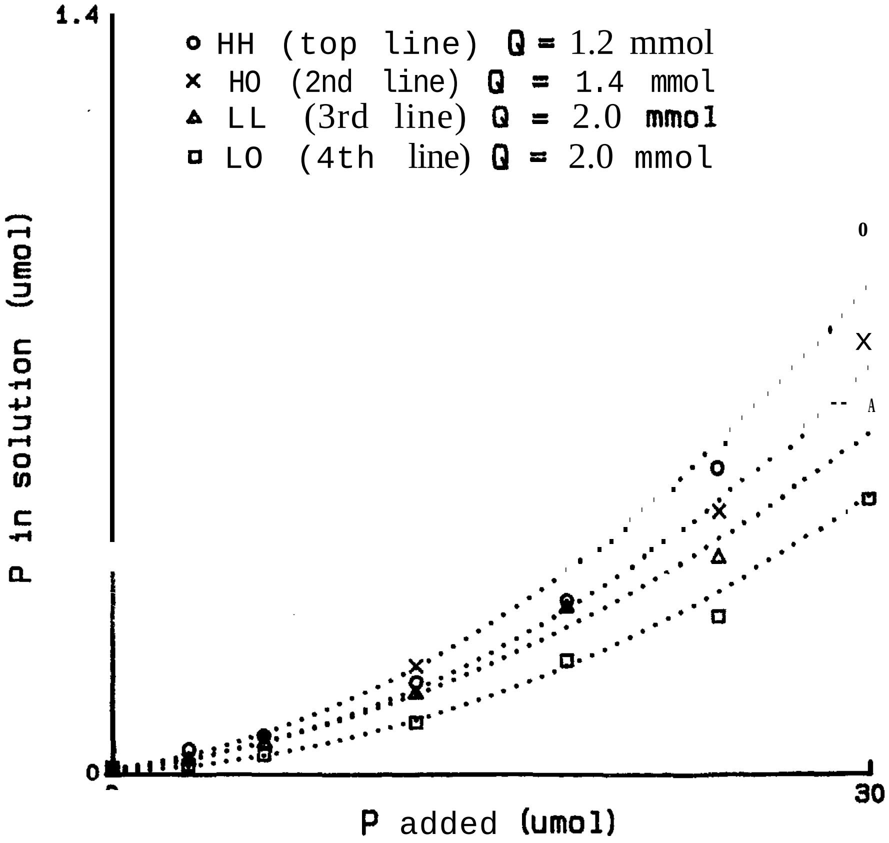

***Figure 3:** Response of solution phosphate, [P], to P addition, PA, to soils of different P history. HH = 630 kg superphosphate/ha/yr; HO = 630 kg/ha/yr discontinued; L L = 125 kg/ha/yr; LO = 125 kg/ha/yr discontinued. Fitted lines are of $[P] = b + PA - Q(1 - (1/(1 + aPA)))$.*

DISCUSSION

Results confirm that the arbitrary division of phosphate applications into capital and maintenance dressings does not describe two separate mechanisms. The quantity of phosphate added, both in the past and currently being applied, determines the efficiency of use of the current applications. The sorption capacity and the strength of bonding of phosphate by the soil is reduced with phosphate input. In terms of converting applied P to solution P, part of the maintenance dressings must therefore be regarded as capital input. While not immediately available, a fraction of the maintenance fertiliser applied has acted to improve the efficiency of the system. If the maintenance dressings are withheld, not only does the system suffer a lower solution P level, but the efficiency of utilisation of subsequently applied phosphate is also reduced.

This concept has been derived from the effect of applied phosphate on the phosphate concentration of the solution in equilibrium with the soil. This fraction is most sensitive to change in phosphate input, but it is also the fraction which provides the driving force on the plant uptake mechanism, and determines the rate of uptake of phosphate by the plant. While not the major fraction of the total available phosphate, it is the sole fraction available at a given time, and in a given soil, it also correlates well with the quantity of phosphate available for solubilisation (Mouat 1983).

The supply of P available to a plant is considered to include the soil's ability to continue to supply phosphate to the solution as the solution is depleted through uptake (Ozanne & Shaw 1967), and this renewal can be interpreted as a desorption by the plant roots (Parfitt et *al.* 1982). Under phosphate responsive conditions, plant growth is limited by the concentration of phosphate in solution. No amount of buffering capacity will give an increase in this concentration. Buffering can reduce the rate of decline of solution concentration, but it cannot give the needed increase. This buffering capacity is of course, the same system which withholds the added phosphate from solution. It is thus intimately linked with the "capital" requirements of the system and the question may be asked – may this "capital" be withdrawn? In the absence of applied phosphate, previously applied phosphate held by the soil can become available (at ever decreasing concentration) to the soil solution. However, removal of this fraction from the buffer will shift the balance of adsorbed to solution phosphate to the disadvantage of solution phosphate, an effect noted in Fig. 3. This will cause a reduction in the efficiency of phosphate subsequently applied. The important concept is that it is the concentration of the phosphate in solution and not the total potentially available phosphate that determines the rate at which the plant will grow. For example, the total available phosphate may be sufficient to produce 10 t DM/ha but how long it takes to produce that depends on the concentration of the phosphate in solution. At 10 µmo1/1 it may take less than a year; at 2 umo1/1, more than 5 years.

The beneficial effects of phosphate fertilisation will still be felt in later years (Lambert et *al.* 1982) and if this residual effect is used as a base for continued application, more and more efficient systems may be developed, but if P application is withheld, and these reserves are "cashed in", then not only will the pasture production be reduced through the lowering of solution phosphate concentration, but also the efficiency of utilisation will drop off as the "capital" status of the system is reduced.

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