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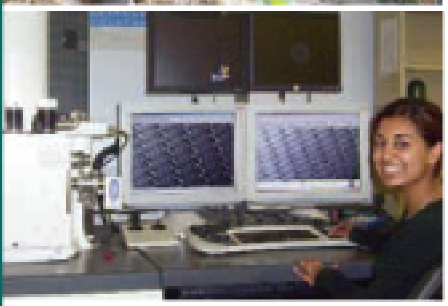
## Reconciling changing concepts of soil phosphorus behaviour with agronomic information



The Fertilizer Institute
Nourish, Replenish, Grow

IPNI International Plant Nutrition Institute

Institut Mondial du Phosphate

International Fertilizer Industry Association

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# Efficiency of soil and fertilizer phosphorus use

## Reconciling changing concepts of soil phosphorus behaviour with agronomic information

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by

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# List of acronyms and abbreviations

| | |
|---|---|
| Al | Aluminium |
| AM | Arbuscular mycorrhiza |
| Ca | Calcium |
| Cu | Copper |
| DAP | Di-ammonium phosphate |
| DCP | Dicalcium phosphate |
| DCPD | Dicalcium phosphate dihydrate |
| DM | Dry matter |
| Fe | Iron |
| FYM | Farmyard manure |
| GPS | Global Positioning System |
| IFA | International Fertilizer Industry Association |
| IPI | International Potash Institute |
| IPNI | International Plant Nutrition Institute |
| K | Potassium |
| LDC | Least-developed country |
| M | Mol |
| MAP | Mono-ammonium phosphate |
| MCP | Monocalcium phosphate |
| Mg | Magnesium |
| N | Nitrogen |
| Na | Sodium |
| OCP | Octacalcium phosphate |
| P | Phosphorus |
| Pi | Inorganic phosphorus |
| Po | Organic phosphorus |
| PR | Phosphate rock |
| RPR | Reactive phosphate rock |
| SDC | Swiss Development Cooperation |
| SOM | Soil organic matter |
| SP | Superphosphate |
| SSNM | Site-specific nutrient management |
| SSP | Single superphosphate |
| TCP | Tricalcium phosphate |
| TSP | Triple superphosphate |

# Executive summary

The efficient use of fertilizer phosphorus (P) is important for three main reasons. First, phosphate rock, from which P fertilizers are manufactured, is a finite, non-renewable resource, and it must be used efficiently in order to maximize its life span. Second, there is a need to maintain and improve the P status of many soils for the growth of crops for food, fibre and bioenergy. This is particularly important in least-developed countries (LDCs) that need to increase food production and improve rural livelihoods. Third, the transfer of soil P (derived from fertilizers and organic manures) is a major cause of P-induced eutrophication in surface waters. This causes undesirable changes in their ecology, resulting in a decline in the provision of eco-services, often with serious economic consequences.

This report reviews, analyses and synthesizes information on the efficient use of soil and fertilizer P. It presents information on the plant availability of soil and fertilizer P, with an emphasis on soil–plant interactions. The focus is on the changing concepts of the behaviour of both soil and fertilizer P and on the need to define and assess their recovery and, thus, P-use efficiency, more appropriately. The report also outlines strategies for improving P-use efficiency.

The main conclusion of this report is that the efficiency of fertilizer P use is often high (up to 90 percent) when evaluated over an adequate time scale using the balance method.

The two main factors controlling the availability of soil P to plant roots are the concentration of phosphate ions in the soil solution and the ability of the soil to replenish these ions when plant roots remove them, i.e. the P-buffer capacity of the soil. Root length and diameter and the efficiency of P uptake by the roots determine the rate and extent of P uptake.

Understanding of the behaviour of P in soils has improved substantially in recent years. Research indicates that inorganic P exists in most soils in adsorbed forms, which can become absorbed by diffusive penetration into soil components. This may result in only a temporary decrease in plant availability (i.e. there is a reversible transfer of P between available and non-available forms). These findings have largely been responsible for the re-assessment developed in this report. It is concluded that P is largely retained by soil components with a continuum of bonding energies, resulting in varying degrees of reversibility. This conclusion is consistent with the often high values (up to 90 percent) for the recovery of fertilizer P over an appropriate time scale. This implies a high efficiency of use over time.

An important outcome of these findings is that soil P can exist in a series of "pools", which can be defined in terms of the extractability of P in different reagents. In turn, the P in these pools can be related to the availability of P to plants, recognizing that there is a continuum of both extractability and availability. If the readily-extractable pool provides most of the plant-available P in soils, then it is only necessary to accumulate and maintain a certain amount of P in it in order to obtain an optimal crop yield. This concept of a "critical value" for a given soil and farming system has important practical implications for efficient P use. Maintaining the soil at or close to the critical value has important benefits to the farmer (in terms of economic return) and to the environment (in terms of reducing the risk of P transfers to surface waters). This concept is less relevant in LDCs as soils usually contain small amounts of available P.

It is possible to define a critical value for readily plant-available soil P for individual soil types and farming systems. This report provides examples and methods to achieve and maintain the critical value. Where adequate information is lacking, it is possible to use an "omission plot" technique to establish whether the soil contains sufficient available P for economically viable yields. Where P limits plant growth, field experiments must determine the amount required.

Phosphorus-use efficiency depends on soil P status, but measurements of P recovery also depend on crop yield, which can be affected by many factors, including other inputs (e.g. fertilizer nitrogen). To build up soil P to the critical value, it may be necessary to accept a lower recovery of added P for some years. In many arable cropping systems, the amount of P required to maintain the critical value is often similar to that removed in the crop (i.e. there is a very high P-use efficiency). Where soil P levels are well above the critical value, P applications can be withheld until soil analysis shows that the value has fallen to near the critical value. Animal production systems can have a positive P balance and an apparent inefficient use of added P. This is largely because of the inefficient recycling of P in dung.

Part of the P added to soil in fertilizer and manure is used by the plant in the year of application. A varying but often substantial part accumulates in the soil as "residual P". This reserve can contribute to P in the soil solution and be taken up by crops for many years. Thus, it is essential to measure this continuing uptake of P over several years in order to obtain reliable results for the recovery and efficiency of use of P. Where the amount of readily-plant-available soil P is below the critical value, the rate of P release from residual P may not be sufficiently rapid to supply enough P to produce optimal yields of the high-yielding cultivars of many crops. In these situations, P must be added in order to achieve the critical value required.

Of the methods for calculating the recovery and efficiency of fertilizer P, the "balance method" is preferred because it takes residual P in the soil into account. It expresses total P uptake by the crop as a percentage of the P applied. The "difference method" considers the difference in P uptake by crops with and without added P as a percentage of the applied P. However, the P taken up by the crop comes partly from freshly-applied P and partly from residual P in the soil from previous applications. Replacing the P taken up from residual P (to prevent P mining and loss of soil fertility) is an integral part of the efficient use of an application of P fertilizer. Therefore, the balance method is preferable to the difference method.

The fact that crops can recover previously applied fertilizer P over quite long periods demonstrates that P is not irreversibly fixed in unavailable forms in soils. It also implies the reversible transfer of P between readily plant-available and less-readily plant-available forms, and that this is an important process influencing the long-term availability of P in soils. Therefore, it is suggested that the design of some existing long-term experiments be modified in order to measure the availability of residual P over a number of years.

Strategies for improving the efficiency of use of soil and fertilizer P include: (i) modifying surface soil properties; (ii) managing surface soil; (iii) managing P sources; and (iv) optimizing P use through economically appropriate rates and timing. Some of these strategies are site-specific and cropping system specific. Although they may have only a small impact individually, in combination their benefits may be significant. However, their costs and benefits will largely determine their adoption.