Soil 'Organic' Phosphorus: An Untapped Resource for Crop Production?

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Farmers in Scotland prepare a field for planting by spreading and incorporating manure.

Phosphorus is essential for plant growth and since its discovery 350 years ago, the use of P fertilizers has significantly increased crop production. However, for plants to take up P it must be: a) in the right form as inorganic free ions, and in solution; b) in the right place at the soil root interface; and c) available at the right time when the crop demands. However, a significant portion of applied P fertilizer is not taken up by plants in the first year (Syers at al., 2008), which can then become unavailable to plants. This is due to a number of confounding factors. Soils vary in their capacity to fix P because phosphate ions have a propensity to: a) form complexes with other soil minerals and constituents including Fe, Al, and Ca; b) adsorb to the soil solid surfaces; and c) be taken up by soil organisms and then converted to organic forms following metabolization, excretion, and decay. Following such adsorption and conversions, P is not readily plant available.

Historically, agronomic management strategies have coped with such phenomena by relying on saturating the system with P, using fertilizers derived from non-renewable rock phosphates, manures and wastes, thus ensuring adequate P for crop growth (Syers et al., 2008). This practice has led to a build-up of soil 'legacy' P (Haygarth et al., 2014). Could this P 'bank' represent an untapped hidden reserve? How much of crop P could this 'bank' provide? What agronomic management strategies would be needed to efficiently use this resource? What is the research community doing?

SUMMARY

Soils with a history of P fertilizer application may represent a significant 'bank' of residual soil P. The P research community offers potential and emerging strategies for land managers to access this soil resource to create sustainable P management strategies that may rely less on inorganic fertilizers and aid in closing the P cycle.

KEYWORDS:

organic P; P 'bank'; P cycle; residual P

ABBREVIATIONS AND NOTES:

N = nitrogen; P = phosphorus; Ca = calcium; Fe = iron; Al = aluminium

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How much of phosphorus crop requirements could this 'bank' provide?

Estimates suggest that between 1965 to 2007 there has been an accumulation of over 1,115 kg P/ha in croplands of Western Europe (Sattari et al., 2012). As there has not been significant decrease in P application since this period, soil stocks are expected to be similar today. A recent review by Menezes-Blackburn et al., (2018) estimated that approximately 57% of the global soil P 'bank' is in inorganic form and 33% in organic form, or broadly speaking, any P compound associated with a carbon atom. Potentially this would provide approximately 201±23 and 117±6 years of P for agronomic use from these respective pools (Menezes-Blackburn et al., 2018). This equates to about 352±26 years of agricultural production at current P offtake rates. Some data used by Menezes-Blackburn et al., (2018) is presented in **Figure 1**. The majority of soils show available P (Olsen P) is well above recommended levels, with significant levels of other forms that represent a potential P 'bank'.

What agronomic management strategies would be needed to efficiently use this soil P 'bank'?

The first obvious strategy to increase the use of the soil residual P 'bank' would be to ensure only recommended amounts of P fertilizer are applied to soil. Simply suspending P application to agricultural soils would put many crop production systems into arrest, even if those soils had a high residual P 'bank' (Nawara et al., 2018). This is because readily available soil P would deplete at rates faster than the solubilization and desorption of the residual P 'bank', causing a net loss of available P. Further work needs to be done to calculate the economic trade-off between net loss of crop yields against the savings made on P fertilizer across different crop and soil types, accounting for crop market value, and P fertilizer costs. This would allow land managers and farmers to implement sustainable P strategies while remaining economically viable. However, this would also require further developments in residual P research to establish necessary model parameters.

Secondly, coupling reductions in P fertilizer application rates with agronomic strategies that actively promote P desorption, solubilization, and mineralization may be more attractive in some agricultural systems. For example, research investigating the implementation of intercropping systems to increase plant uptake of soil organic P has provided promising results. Work by Giles et al., (2017) showed that intercropped legume and barley cultivars with varying root exudate and morphological traits related to varying uptake of residual P forms. By calculating the Land Equivalent Ratio (Darch et al., 2018) of such systems, these data can be used to estimate the loss of productive land and savings on P fertilizer made by employing intercropping systems. Such work employs crop choice and land-management techniques to increase use of the soil residual P 'bank'. Several studies have also been conducted in legume-based grazing systems where cultivar choice can have significant impacts on P fertilizer use efficiency and reduce demands on N (Haling et al., 2016).

Contrasting work in arable cropping systems in North Western Australia demonstrated that deep placement of P fertilizer can improve both P and water use efficiency (Lester et al., 2018).

Other strategies look towards reducing additions of P in organic forms that contribute to the residual P 'bank'.

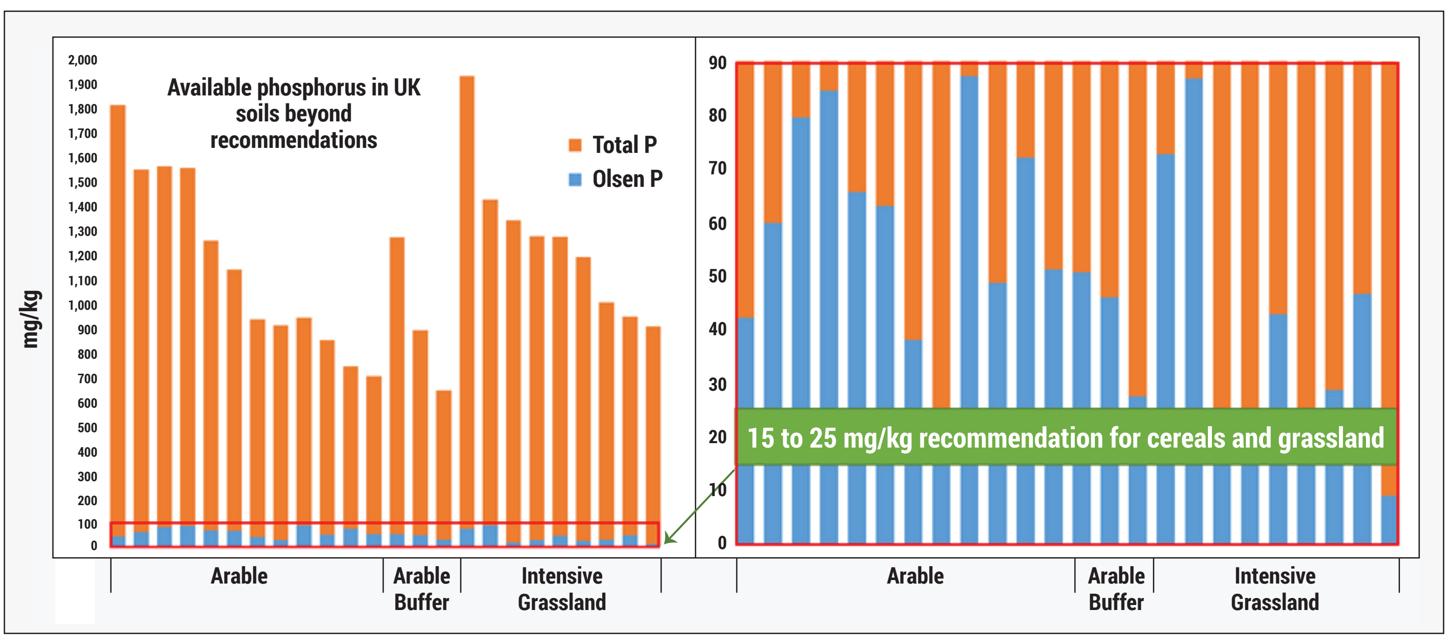

Figure 1. Phosphorus forms in a range of UK agricultural soils (Taken from: Stutter et al., 2015). These data show that the majority of soils have Olsen P test values above recommendations and represent a significant P 'bank' for potential plant use.

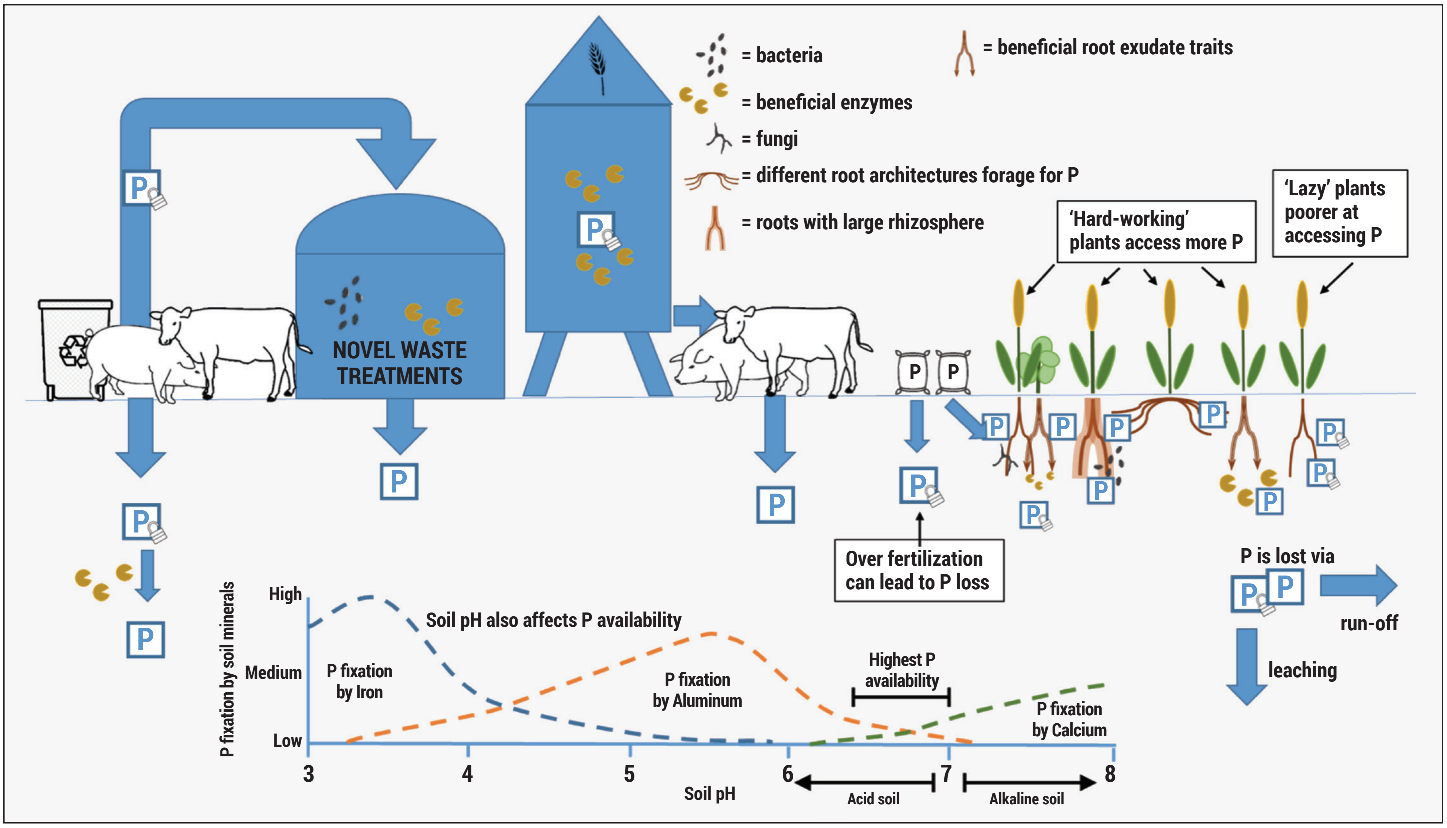

Figure 2. Management practices and technologies available to improve soil phosphorus use by crops and pastures which could aid in closing the phosphorus cycle.

Manures, specifically those from monogastric livestock fed on grain diets contain significant amounts of recalcitrant organic P forms (Turner et al., 2002). One strategy is to reduce grain consumption by livestock, thereby reducing the amount of recalcitrant P forms entering the system. In addition, the application of specific enzymes capable of hydrolyzing organic to inorganic P forms can be employed at various stages to increase P bioavailability. Direct application of enzymes to grain prior to livestock consumption is a practice already prevalent in the feedstock industry, or after field application of manures, slurries, and digestates. However, treatment of manures prior to application could result in the overloading of soluble P sources to the system. Such scenarios could pollute the natural environment via run-off or leaching, or could become sequestered prior to crop demand. The P research community offers the fertilizer industry novel opportunities for the development of more economically and environmentally sustainable P sources, including strategies that tap into legacy P stores in agricultural soils. Engaging such opportunities has potential to place the industry at the forefront of tackling such global challenges as food security and environmental protection. Some of these strategies are illustrated in **Figure 2**.

What is the phosphorus research community doing?

Many promising technologies and agronomic management strategies exist that have the potential to significantly increase the use of the soil residual P 'bank', thus reducing demands on phosphate rock-based fertilizers. There is a consensus that a multi-pronged approach by both land managers and the research community will be required for the proper design and implementation of sustainable P management strategies. This will need to be on a case-by-case basis as soil type, management practice, and soil P status vary greatly.

TAKE IT TO THE FIELD

Understanding the total P in field soil can offer potential for using the soil residual P 'bank' on agricultural land. The adoption of multi-pronged approaches from P research can aid in the development of on- and off-farm sustainable P management strategies.

The proposed consideration of the soil residual P 'bank' directly addresses the two main tenets of the statement of intent declared by members of the P research community who attended the international organic phosphorus workshop in 2016:

(i) To reduce our reliance on inorganic P fertilizers, as strategies to do this will increase the relevance of soil organic P for plant nutrition.

(ii) A need to develop a more circular P cycle, which will likely lead to an increase in the amounts of organic P 'waste' products being recycled to land (George et al., 2018).

To achieve the necessary impact of soil P research, there is a need to engage researchers outside of the discipline, align the research with pressing societal issues, and become more global, collaborative, inclusive, interdisciplinary, and longer-term in nature. Also, the key to fostering this change will depend on logically communicating with stakeholders, and ultimately pushing this important area of research up the agenda of policy makers and funding bodies on a global scale (George at al., 2018). **BC**

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