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COMMENTARY

Terminology for residual and legacy phosphorus

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Abstract Phosphorus accumulation in agricultural soils is a growing concern worldwide, but terminology on this issue is confusing. The accumulated phosphorus is often described as *residual phosphorus*. However, agronomists use this term for the fertilizer not taken up by the crop, and soil scientists use it to describe the phosphorus remaining in soil after sequential extraction, a procedure used to characterize the chemical nature of soil phosphorus. These different uses of *residual phosphorus* are mutually incompatible because phosphorus accumulated in the soil is often readily soluble, while phosphorus remaining after sequential extraction is extremely stable. To resolve this, we endorse the term *legacy phosphorus* to describe the phosphorus accumulated in soil through human activity, based on the definition of legacy as *something received from the past or carried over from past actions*. This allows the term *residual phosphorus* to be reserved for the unextractable phosphorus in sequential extraction schemes (i.e., *in the residue, leftover or remaining*). Finally, we recommend the term *surplus phosphorus* for the fertilizer not taken up by the crop, based on the definition of surplus as an *excess of supply over demand*. This clarification of terminology will reduce confusion as research progresses on this interdisciplinary topic.

Keywords Phosphorus · Soil · Fertilizer · Legacy phosphorus · Residual phosphorus · Phosphorus fractionation

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There is considerable current interest in the phosphorus (P) that has accumulated in soils through human activity (Sattari et al. 2012). This accumulation has occurred because phosphate fertilizer is inefficient – only a small proportion of the added P is taken up by the crop each year, resulting in the routine application of P fertilizer far exceeding crop requirements (Hedley and McLaughlin 2005). The accumulated fertilizer represents an enormous potential reserve of P for agriculture, while simultaneously threatening the health of the aquatic environment. As research on this topic intensifies, what should we call the accumulated P?

For agronomists, fertilizer-P not taken up by the crop has long been termed *residual P* and is used to calculate P-use efficiency, defined as the ratio of P uptake by the crop to the P added as fertilizer. This definition of *residual P* is often used synonymously to describe the surplus P that accumulates in the soil. However, not all the surplus P remains in the soil – some is dissolved in soil solution and lost in leachate, while still more is lost in erosion and surface runoff (Haygarth and Jarvis 1999). At the same time, P is added to the system in atmospheric deposition. The surplus fertilizer P therefore differs from the P accumulated in the soil – an alternative term is required to describe the P accumulated through human activity.

There is further confusion because soil scientists use *residual P* to describe the P remaining after sequential P fractionation. This procedure involves the use of chemical solvents to extract P from the soil and partition it into operationally defined fractions based on solubility (Hedley et al. 1982) and is widely used despite its shortcomings (Barrow et al. 2021). In these procedures, *residual P* describes the unextractable forms of soil P that are bound in ways that resist disruption by even strong acids and alkalis. This use of the term *residual P* is pervasive in the literature, dating back to the early use of fractionation schemes in the 1960s.

The different uses of *residual P* have rarely overlapped, but sequential fractionation is now being used routinely to characterize the chemical nature of the P accumulated in soil (e.g., Liu et al. 2017). We are therefore faced with a situation where the soil scientist's *residual P* – arguably the most resistant and unavailable P in the soil – is part of the agronomist's *residual P* that includes the most readily soluble and biologically available forms. For example, a recent study (Sims et al. 2023) reported that almost two thirds of the *residual P* in Minnesota soils (termed *net P* in this study) was in the form of resin-extractable and bicarbonate-extractable P – two of the most readily soluble forms of soil P. In other words, the soil scientist's *residual P* is only a small proportion of the agronomist's *residual P*, which in turn is antithetical to the soil scientist's *residual P* in terms of availability. The soil scientist's and the agronomist's use of *residual P* are mutually incompatible.

To resolve this issue of terminology, we endorse the term *legacy P* to describe the P accumulated in soil from anthropogenic activity. The term appears to have widespread acceptance (e.g., Jarvie et al. 2013; Sharpley et al. 2013; Rowe et al. 2016) and can also be used to describe the P accumulated in aquatic sediments (Lannergård et al. 2020). It has the advantage of indicating the long-term consequence of past actions, based on the definition of legacy as *something received from the past or through past actions or carried over from an earlier time*. *Legacy P* is calculated as the sum of inputs minus the sum of outputs over a given period of time and therefore differs from the agronomic definition of *residual P* because it describes only the P retained in the soil accounting for other inputs and losses, rather than the fertilizer P not taken up by the crop (Rowe et al. 2016). In other words, it differs from the simple calculation of agronomic *residual P*, which is concerned only with the inefficient use of P fertilizer.

The use of *legacy P* allows the term *residual P* to be reserved for the P that remains unextracted in sequential fractionation schemes (i.e., *in the residue, leftover or remaining*). For the phosphate not taken up by the crop (the agronomist's *residual P*) we recommend using *surplus P*. This term is commonly used when describing agricultural P budgets and is appropriate because it signifies something exceeding requirement, based on the definition of surplus as *an amount of something left over when requirements have been met, or an excess of supply over demand*.

Phosphorus research is plagued by issues of terminology. These recommendations will help to resolve the emerging problem with the term *residual P* as research progresses in this interdisciplinary topic.

Declarations

Competing interests The authors declare no competing interests.

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