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The phosphorus transfer continuum: Linking source to impact with an interdisciplinary and multi-scaled approach

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Abstract

This critical review introduces a template that links phosphorus (P) sources and mobilisation processes to the delivery of P to receiving waters where deleterious impact is of concern. It therefore serves as a key introductory paper in this special issue. The entire process is described in terms of a 'P transfer continuum' to emphasise the interdisciplinary and inter-scale nature of the problem. Most knowledge to date is derived from mechanistic studies on the sources and mobilisation of P using controlled experiments that have formed the basis for mitigation strategies aimed at minimising transfer from agricultural fields. However, our ability to extrapolate this information to larger scales is limited by a poor knowledge base while new conceptual advances in the areas of complex systems and fractal dynamics indicate the limitations of past theoretical frameworks. This is compounded by the conceptual and physical separation of scientists working at different scales within the terrestrial and aquatic sciences. Multi-scaled approaches are urgently required to integrate different disciplines and provide a platform to develop mechanistic modelling frameworks, collect new data and identify critical research questions.

Keywords: Phosphorus; Source; Mobilisation; Detachment; Solubilisation; Incidental; Delivery; Impact; Eutrophication

1. Introduction

Phosphorus (P) transfer from agricultural soil to water has attracted increased attention in the last decade, but it remains difficult to achieve a balanced consensus on critical issues. The amounts of P transferred from agricultural soils are small compared with those added to soil as mineral fertilizer and manure. For example, total P losses from soil are in the order of 1 kg ha^{-1} year^{-1} (Haygarth and Jarvis, 1999), whereas annual fertilizer and manure inputs are typically between 20 and 50 kg P ha^{-1} year^{-1} (Cameron et al., 2002; Haygarth et al., 1998b). In

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terms of the mechanisms of P transfer, several studies highlighted the importance of soil erosion and physical transfer of P with soil particles from land to water, for example on arable soils in the mid-western USA (Sharpley, 1985; Sharpley and Smith, 1990). Other studies stressed the importance of fertilizer inputs, soil P concentrations (Heckrath et al., 1995), and manure inputs (Greatz and Nair, 1995; Lanyon, 1994). Added complexity arises from confusing terminology for the forms of P and the processes and pathways of their mobilisation and transfer: Table 1 provides a reference for key terms and definitions: it goes beyond that provided by Haygarth and Sharpley (2000).

This paper presents a critical review of P transfer research, outlining why we believe progress is being stifled and offering ways that this can be remedied. There is insufficient interaction between scientists in different disciplines, with the result that views become confined to the scale of focus and the methodology of each individual discipline. In particular, debate about control of P transfer is currently based mainly on data from soil science and agronomy, yet the problem is manifested, explicitly, in limnology. This presents a difficulty, because soils scientists tend to favour reductionist approaches that test hypotheses, dissecting processes at increasingly finer scales. In strong contrast, limnologists favour observational and empirical approaches, identifying patterns in lotic and lacustrine systems that, by their very nature, are integrated and 'lumped' at the large scale. The result is that the current research questions that drive the subject forward are inadequate because they do not cross disciplinary boundaries.

A coalition of disciplines within the land–water continuum is required, aimed at producing a truly integrated approach to the problem. This is in part the aim of this special issue and also of this introductory overview paper. If this can be achieved, new and critical research questions will emerge to define a more effective approach to P transfer. Here, a template for linking P transfer from source to impact is provided using an interdisciplinary and multi-scaled approach. This simple conceptual framework involves selected (but by no means complete) use of representative citations from soil scientists, agronomists, hydrologists, chemists, ecologists, limnologists, modellers, policy makers and regulators. By presenting and discussing the problem in an interdisciplinary context, we hope to evolve a coherent structure for synthesising research and understanding of this complex issue.

2. The phosphorus transfer continuum

We adopt a simple source-mobilisation-delivery-impact structure to organise the discussion. This is similar to classical 'source-pathway-receptor' models that are well proven. Its evolution can be traced back to indexing approaches (Lemunyon and Gilbert, 1993), the arrangement of a European Research Programme (Withers, 1997), conceptual models (Haygarth and Jarvis, 1998, 1999), the structure for an international conference (Haygarth et al., 2001), and approaches which also formed the focus of modelling frameworks (Heathwaite et al., 2003). This four tiered framework is called the 'P transfer continuum' to emphasise the interdisciplinary and interconnected nature of the science (Fig. 1).

2.1. Sources

The input of P to soil creates the potential for an increase in transfer to the wider environment. Phosphorus sources can be natural (indigenous soil P and atmospheric deposition) and anthropogenic (fertilizers and animal feed input to the farm, fertilizers and manure applied to the soil). Most research examining diffuse P sources has been conducted in intensively managed agro-ecosystems, where continued inputs of P as mineral fertilizers and imported animal feed result in the accumulation in topsoil (Condron, 2004; Haygarth et al., 1998a). Imported feed is particularly important in areas of intensive livestock production where large quantities of manure are applied to land (Sharpley and Tunney, 2000). The spatial distribution of the various source inputs of P across the landscape creates a complex and dynamic mosaic of potential P sources, because the inputs vary within the 'agricultural year' (e.g. timing of manure and fertilizer applications) and over longer timescales (e.g. in response to economic drivers such as reform of European Union Common Agricultural Policy) (Heathwaite et al., 2003).