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Role of legacy phosphorus in improving global phosphorus-use efficiency

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The manuscript by Ulrich et al. (in press) describes and discusses key large scale international policy and communication issues associated with the development of appropriate responses to improving the utilisation of global phosphorus (P) resources. In particular the paper outlines the need for an integrated and holistic-multidisciplinary approach to deal with historic and ongoing high inputs of P to intensively managed agroecosystems. This commentary is designed to complement the Ulrich et al. manuscript by highlighting the vital role of "residual" or "legacy" P in tightening P cycling to maintain productivity in farming systems with reduced P inputs and minimise P transfer from land to water.

It is well established that most of the P applied to agroecosystems in the form of mineral fertilisers, manures and wastes is retained in the soil as inorganic and organic P that is otherwise only sparingly available to plants. For example, accumulation of P in soil under cropping in Western Europe between 1965 and 2007 amounted to over 800 kg P ha^{-1} (Sattari et al., 2012), which included significant quantities of organic P in the form of phosphomonoesters (Stutter et al., 2012). Whilst this legacy P accumulated in the soil has enormous potential to 'off-set' fertilizer inputs, it also represents a significant environmental risk – if not appropriately managed, the accumulated P can cause enhanced eutrophication of rivers, lakes and estuaries, resulting in wide spread loss of socioeconomic value in these systems and accumulation of P in depositional zones.

Improved utilisation of legacy P across all environmental systems could, in many cases, allow a reduction or more strategic use of P inputs, although the time required to reduce soil P levels to agronomic optima may take decades and may not be in line with existing policy timelines (Dodd et al., 2012; Sharpley et al., 2013). We contend that there is considerable potential to enhance the bioavailability and utilisation of residual inorganic and organic P resources in soil using biological means. Plant breeding and

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genetic modification could be employed to improve P-use efficiency (Wu et al., 2013), whilst changes in farm management and more precise farming practices, along with inclusion of manure legume crops, could be used to enhance utilisation of sparingly available inorganic P and organic P in soil (Haygarth et al., 2013). Greater understanding of plant–soil microbiome interactions and soil fertility management (i.e. critical requirement of different systems) may also provide new opportunities for improvement (Richardson et al., 2011). The addition of phytase enzymes to grain-based animal feed is one example where a small adjustment to management has had a dramatic effect on increased organic P utilisation and reducing P in waste (Lei and Porres, 2007). In terms of our degraded aquatic ecosystems, P management for the improvement of water quality should be considered alongside resource recovery from legacy P stores. Recent developments in our understanding of microbial processing of 'refractory' P compounds (McGrath et al., 2013) and in our ability to short-circuit organic P pathways using geo-engineering (Spears et al., 2013) represent two potential measures for achieving more flexible water resource management in this respect. Increased knowledge of ecosystem response times following implementation of various P management measures designed to improve the utilisation of legacy P in intensive agroecosystems is required to develop appropriate timelines for corresponding environmental policy.

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