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Review

A review of recent substance flow analyses of phosphorus to identify priority management areas at different geographical scales

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ABSTRACT

The dwindling global reserves of extractable phosphorus (P) and its growing demand to produce the required food for a burgeoning global population (the global P crisis) necessitate the sustainable use of this crucial resource. To advert the crisis requires informed policy decisions which can only be obtained by a better understanding of the nature and magnitude of P flow through different systems at different geographical scales. Through a systematic and in-depth review of twenty one recent substance flow analyses of P, we have assessed the key P inflows, outflows, stocks, internal flows, and recycling flows at the city, regional, and country scales. The assessment has revealed, the main inflow and outflow of P at the city scale occurs through food and wastewater respectively, while the main stock of P occurs in landfill. At the regional scale, mineral ore is the main P inflow and chemical P fertilizer is the main outflow particularly in the regions that have P fertilizer production sector. In contrast, either chemical P fertilizer or animal feed is the key inflow and either food and agricultural products or soil losses (erosion, runoff, and/or leaching) is the major outflow especially in the regions without P fertilizer production sector. At the country scale, the key P inflow occurs either through mineral ore or chemical P fertilizer and the key outflow takes place either as food and agricultural products, waste (both solid and liquid), or soil losses (erosion, runoff, and/or leaching). The main stock of P both at the regional and country scales occurs in the soil of the agricultural production sector. As identified in this assessment, the key unproductive outflows and stocks at different geographical scales indicate that there is a potential scope to improve P management through the increased P recovery and recycling, and by the utilization of available soil P stocks. In many of the studies at all the geographical scales, P recycling flow has been found to be less than 20% of the total inflow, and even in some studies at the country scale, P recycling has been found to be entirely absent, which is a clear indication of poor P management. This study has also identified, there is a clear knowledge gap in relation to understanding the P flow over multiple years at the regional scale. The information about the key flows and stocks at different geographical scales as we identified can be utilized to make better P policy and management decisions for a city, region, or country. The information can also be used to guide future research that aims to analyze P flow at the city, regional, and country scales.

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1. Introduction

The issue of the global phosphorus (P) crisis and its threat to global food security is not new. It has been well addressed in the published literature (Cordell et al., 2009; Gilbert, 2009; Smit et al., 2009; Vaccari, 2009; Schroder et al., 2010; Ashley et al., 2011; Childers et al., 2011; Cordell and White, 2011; Dawson and Hilton, 2011; Elser and Bennett, 2011; Elser, 2012; Neset and Cordell, 2012) over recent years. Even a few years back, Cordell et al. (2009) argued, in spite of P being a limited, non-renewable and non-substitutable but very crucial resource for sustaining global food production, the issue of the global P crisis is missing from the key international debates on global food security. This attitude has changed over the last few years, and the global P crisis is now considered amongst the biggest challenges to the existence and development of global population. For instance, the UNEP (United Nations Environment Programme) Year Book (UNEP, 2011) titled 'Emerging Issues in Our Global Environment' emphasized the necessity of sustainable P management for achieving global food security and minimizing environmental pollution. In 2011, two special journal issues titled 'Phosphorus Sustains Life' (Rengel and Zhang, 2011) and papers therein, and 'The Phosphorus Cycle' (Vaccari, 2011a) and papers therein, and in 2012, one special journal issue titled 'Phosphorus Biotechnology' (Shilton and Blank, 2012) and papers therein have been published on different aspects of P research. In response to the global P crisis, some scientists have been even looking for P substitutes. For instance, a NASA study claimed that arsenic could substitute for P to sustain growth of a bacterium, strain GFAJ-1 of the Halomonadaceae found in the Mono Lake, California (Wolfe-Simon et al., 2011). Thus, it is apparent that the global scientific community is now aware of the importance of this issue, and has concentrated its research efforts to find a way of achieving sustainable management of P resources to feed an increasing global population.

To tackle the global P crisis and to secure a sustainable supply of P for global food production, an integrated set of policy options and technical measures that ensures efficient management of this vital resource are required at the local, national and international scales (UNEP, 2011). Formulation of better policy and management response in turn requires a better understanding of the nature and magnitude of P flow through different systems at different geographical scales, and efforts are underway to identify this information. A number of recent studies conducted quantitative assessments of P flow through different systems at various geographical scales such as the global scale (Liu et al., 2008; Villalba et al., 2008; Bouwman et al., 2009; Van Vuuren et al., 2010), multiple country scale (Ott and Rechberger, 2012), country scale (Antikainen et al., 2005, 2008; Saikku et al., 2007; Chen et al., 2008; Fan et al., 2009; Jeong et al., 2009; Matsubae-Yokoyama et al., 2009; Seyhan, 2009; Dairy Australia, 2010; Smit et al., 2010; White et al., 2010; Ghani and Mahmood, 2011; Suh and Yee, 2011; Ma et al., 2012; Senthilkumar et al., 2012; Cooper and Carliell-Marquet, 2013; Cordell et al., 2013), regional scale (Neset et al., 2008; Li et al., 2010; Do-Thu et al., 2011; Yuan et al., 2011a,b; Wu et al., 2012), city scale (Tangsubkul et al., 2005; Neset et al., 2010; Baker, 2011; Fissore et al., 2011; Qiao et al., 2011; Metson et al., 2012a), and some studies at smaller geographical scales (Baker et al., 2007; Kupkanchanakul and Kwonpongsagoon, 2011). These quantitative assessments allowed the researchers to identify the nature and magnitude of P wastage from the system, and thus helped to ascertain the potential for minimizing P loss, and increasing P recovery and reuse. Based on the outcome of the assessments, these studies were also able to suggest improved site specific P management decisions.

Although a considerable number of P flow analyses have already been conducted at different geographical scales, we are unaware of any systematic review of the available knowledge to provide baseline information about the nature and magnitude of geographical scale specific key P flows and stocks. This baseline information could be very useful to identify geographical scale specific priority areas of P flow which is in turn a requisite for making better P management decisions. Due to variation in the spatial extent as well as in the availability and size of different sectors of P use, the nature and magnitude of major P flows may vary from one geographical scale to another. The type and magnitude of key P flows for the same geographical scale can also differ from one country to another and even from one location to another within the same country. Thus, understanding the variations and similarities of the type and magnitude of the main P flows at various geographical scales as well as at different locations for the same geographical scale is essential to generate baseline information about geographical scale specific key P flows and stocks. Through a systematic and in-depth review of twenty-one recent analyses of P flow, we attempt to evaluate the nature and magnitude of the key P flows and stocks at the city, regional, and country scales. This evaluation will be based on assessing the main inflows, outflows, stocks, internal flows, and recycling flows. Based on this evaluation, we attempt to identify the priority areas of P management at the city, regional, and country scales; and suggest some necessary policy and management initiatives in this regard. We also aim to identify the knowledge gaps in the available P flow analysis literature and discuss options of future research to develop new knowledge for making better P management decisions.

2. Methods of assessment

For this assessment, thirty-two recent analyses of P flow have been initially selected according to the following criteria:

- studies that used Substance or Material Flow Analysis (SFA/MFA) as a method for the quantitative assessment of P flow through a system;
- peer-reviewed articles written in English;
- published between 2005 and 2012;