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Global phosphorus flows through agricultural trade

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ABSTRACT

The global phosphorus cycle has been transformed in recent decades through increased use of mineral phosphorus fertilizer in agriculture and losses to water bodies, leading to risks of fossil phosphorus resource depletion and freshwater eutrophication. By moving phosphorus resources across world regions, international trade of agricultural products (food, feed, fiber and fuel) may contribute to these changes in the global phosphorus cycle, including critical nutrient imbalances. However, we lack a comprehensive, quantitative understanding of the role of agricultural trade in the global phosphorus cycle. By combining detailed data on international trade and the phosphorus content of agricultural products, we demonstrate that phosphorus flows through trade increased nearly eight-fold from 0.4 Tg P/yr in 1961 to 3.0 Tg P/yr in 2011, leading to an increase in the fraction of phosphorus taken up by crops that is subsequently exported from 9% in 1961 to 20% in 2011. The P flows in traded agricultural products was equivalent to 27% of the P traded in mineral fertilizers in 2011. Agricultural P flows were mostly driven by trade of cereals, soybeans and feed-cakes, with 28% of global phosphorus traded in human food, 44% in animal feed and 28% in crops for other uses in 2011. We found a strong spatial pattern in traded phosphorus in agricultural products, with most flows originating from the Americas and ending in Western Europe and Asia, with large amounts of phosphorus moving through trade within Western Europe, in strong contrast with the pattern of the mineral P fertilizer trade. We demonstrate that international trade of agricultural products has affected the domestic phosphorus cycle within many countries, making phosphorus exporters susceptible to the volatility of the mineral phosphorus fertilizer market. Overall, these results highlight the importance of trade as key component of the global phosphorus cycle.

1. Introduction

Phosphorus (P) is a critical element for all living organisms; its availability drives the productivity of many aquatic and terrestrial ecosystems worldwide (Mueller et al., 2012; Peñuelas et al., 2013). In agricultural systems, additional P can be supplied to soils as mineral fertilizer or manure to support crop growth and sustain high yields. However, mineral P fertilizer production is dependent on the physical and economic availability of mined rock phosphate resources, a non-renewable, diminishing, and geopolitically concentrated resource (Cordell et al., 2009; Van Vuuren et al., 2010). The P cycle has been greatly transformed since the pre-industrial era (Bennett et al., 2001; Liu et al., 2016; Maavara et al., 2015) through increased agricultural mineral P fertilizer use (Ringeval et al., 2014; Tilman et al., 2002; Vitousek et al., 2009); this large increase in mineral fertilizer use has been driven by increasing population and shifts towards more meat-based diets, which are known to have low P use efficiency (Metson et al., 2012), in affluent, industrialised, and emerging countries (Lassaletta et al., 2014b; Tilman and Clark, 2014). In other words, the modern farming systems we depend on for food globally are dependent on, and affect, the extraction and movement of phosphate rock resources around the planet. In addition, P losses to water bodies through runoff and erosion from fertilized agricultural soils and from the inadequate management of animal manure or human excreta has led to aquatic eutrophication (Carpenter et al., 1998; Schindler et al., 2008). These issues of scarcity and pollution reflect the need to consider the

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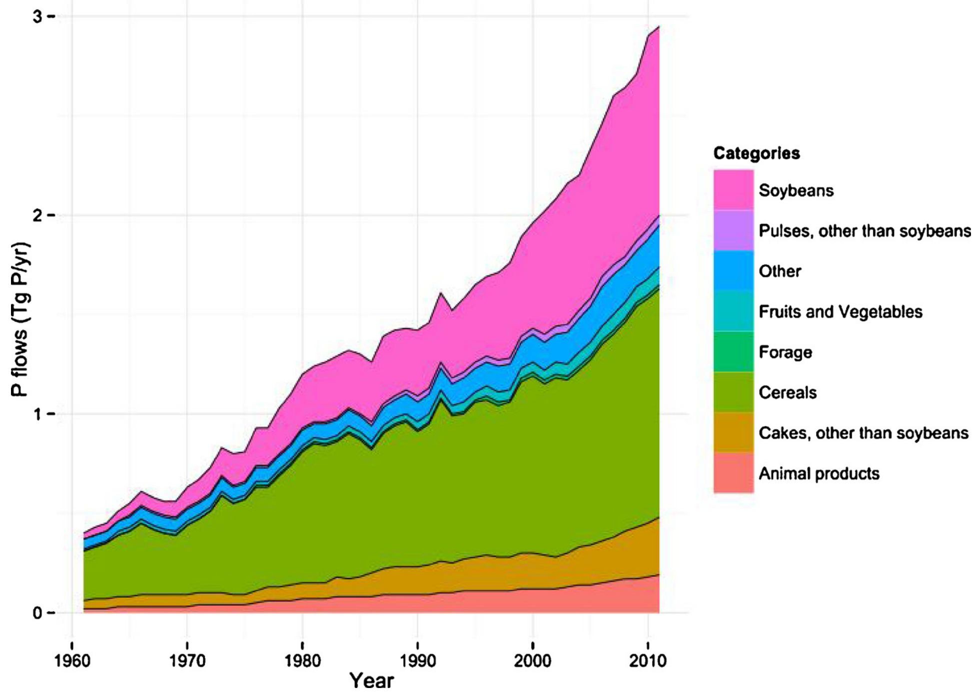

Fig. 1. Total P flows through international trade of agricultural products (in Tg P/yr) from 1961 to 2011.

sustainability of the global P cycle (Cordell et al., 2012) and call for the parsimonious use of mined P resources, limited P accumulation in agricultural soils, increased P use efficiency, and recycling wherever possible (Withers et al., 2015).

The modern era is characterized by intensive trade of agricultural products as food, feed, fibre and fuel, which has accelerated dramatically during the last decades (Krausmann et al., 2008) due to falling transportation costs, trade liberalisation, and the shift of most agricultural production systems towards economies of scale in industrialised and emerging countries (Frankel and Rose, 2005). For instance, the global wheat and rice trade increased by 42% and 90% in just the 17 years from 1992 to 2009, respectively (Puma et al., 2015). The effect of such trade on rock phosphate resource conservation is likely to be large because it can lead to major displacement of P resources embedded in agricultural products, limiting opportunities to recycle P resources locally, e.g. through recycling of P in animal manure back to croplands that produce feed (Schipanski and Bennett, 2012).

However, although there are studies of the intensity of agricultural product trade (Kastner et al., 2014; Krausmann et al., 2008; MacDonald et al., 2015), and of phosphate rock trade (Jasinski and USGS, 2011), the effects of agricultural trade on the global P cycle have never been quantified. Two decades ago, Bouwman and Booij (1998) examined P feed in trade, and more recently Wang et al. (2017) examined P flows associated with agricultural trade in a few selected countries, but we still lack a comprehensive and quantitative understanding of how P flows associated with agricultural trade have affected the global P cycle or the impact this has on overall P sustainability. In particular, an accurate estimation of how much P is displaced between world regions and countries as traded products is needed. Comparing the magnitude and pattern of P flows in traded harvested crop products with the use and trade of mineral P fertilizers can help us to better understand the relative contribution of agricultural product trade on the modern global P cycle. This, in turn, is important for highlighting the spatial patterns of such flows and their drivers, and ultimately for assessing the role agricultural trade may play in increasing (or decreasing) sustainable P management (West et al., 2014). Identifying potential P scarcity and water quality “winners” and “looser” in an increasingly globalized world is can also help make more informed P management decisions about food security and agriculture, globally (MacDonald et al., 2015). Here we quantify the magnitude of P flows through agricultural product trade at the global scale from 1961 to 2011, as well as the spatial patterns of these trade flows in 2011 using FAO data to start to fill the existing knowledge gap related to the importance of trade on the global P cycle. More specifically, we focus on a descriptive and quantitative analysis as a first step towards understanding the impact of modern agricultural trade and we:

i) estimate changes in global P flows through trade
ii) assess the relative contribution of food, feed and other agricultural product trade to global P flows
iii) compare agricultural product trade P flows to the magnitude and patterns of mineral P fertilizer trade flows
iv) preliminary assess the consequences of agricultural product trade for the global P cycle.

2. Methods

Not all agricultural products exhibit the same P concentration making biomass flow a poor indicator of the effect of trade on the global P cycle. For instance, P concentration in palm oil is very low but palm oil is one of the most heavily traded products. In other words, converting all biomass flows into a single unit is necessary to estimate the consequences that global trade has for the global P cycle. We calculated P flows through agricultural product trade among countries by multiplying the weight of agricultural products traded (imported and exported) among countries by their respective P contents (Food Standards Agency, 2002). We obtained the quantities traded among countries for 397 agricultural products from the FAOSTAT trade module (http://faostat3.fao.org/download/T/*/E, accessed on July 3rd, 2017). The FAOSTAT trade module provides annual data on total import and export of crop and livestock products for each FAO country (n = 203) from 1961 to 2011 and on detailed import/export of crop and livestock products among pairs of FAO countries (e.g., from country i to country j) from 1986 to 2011. In this study, we used data on material import only because these data have been reported to be more reliable that export data (see SI). The trade data we used does not account for food aid (but this represents a very small amount of global trade, see