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Commentary

Distant Views and Local Realities: The Limits of Global Assessments to Restore the Fragmented Phosphorus Cycle

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Core Ideas

- Meta-analysis of "big data" can identify P disconnects in P cycles, stocks and flows.
- Understanding of farming realities is needed to identify root causes of change.
- Access to "big data" without grounding in reality can lead to misleading conclusions.
- Researchers must ensure production and conservation tactics consider farming realities.

Abstract: With more sophisticated data compilation and analytical capabilities, the evolution of "big data" analysis has occurred rapidly. We examine the meta-analysis of "big data" representing phosphorus (P) flows and stocks in global agriculture and address the need to consider local nuances of farm operations to avoid erroneous or misleading recommendations. Of concern is the disconnect between macro-needs for better P resource management at regional and national scales versus local realities of P management at farm scales. Both agricultural and environmental researchers should focus on providing solutions to disconnects identified by meta-analyses and ensure that production and conservation strategies consider farming realities.

Over the last 60 yr, global extraction of phosphate rock for fertilizers has tripled to increase agricultural productivity and sustain a growing global population (MacDonald et al., 2012). The use of phosphorus (P) fertilizers has opened up vast tracts of otherwise unproductive farmland, which has improved food security and promoted economies of scale in agriculture, food production, and trade. Even so, there are legitimate and increasing concerns about the global efficiencies and sustainability of society's current use of P, with only a small proportion (<20%) of P mined for fertilizer reaching the food that is consumed (Neset and Cordell, 2012). Large-scale P losses from agriculture and urban areas impair water quality, with profound and widespread detrimental impacts on water security, ecosystem sustainability, and human health (Jarvie et al., 2015).

As nutrient enrichment and related impairment of surface waters continue to expand, many sectors of agriculture have faced increasingly intense scrutiny and, in some cases, litigation (McBride, 2011; Iowa Drainage District Association, 2015; Sharpley et al., 2012). The ensuing implementation of nutrient management strategies and conservation measures is bringing improvements in water quality, albeit more slowly than expected or desired by end-users of those water resources (Sharpley et al., 2013).

Running parallel with water-quality concerns related to P management in different sectors of agricultural production is the growing recognition that not only are supplies of mineral rock P finite, but there is an absence of a coordinated strategy for P conservation and recovery (Scholz et al., 2015). This abundance–scarcity paradox has stimulated assessments of global flows, stocks, and stores of P, using a plethora of regional and global datasets. With greater access to more sophisticated data compilation, storage, computing power, and analytical capacity, the evolution and use of meta-analysis have expanded rapidly. Indeed, greater availability of data has created opportunities for different agendas and narratives to be elevated above the level of local, agricultural production concerns, expanding the scope of perspective. However, the disparities in scale between global assessment of P cycling and local social, environmental, and economic factors, determining farm management, can mean that recommendations

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based on these assessments are sometimes devoid of practical reality and incorrect in extrapolation.

Given the growing trend of regional and global P studies, we examine and critique the meta-analysis of "big data" representing P flows in global agriculture and review the likely collateral, or unintended, impacts of recommendations that these studies sometimes produce. In particular, we focus on the need to consider the social, economic, and environmental realities of farming systems in the United States and many other regions of the world to provide long-term solutions that sustain food production and limit water-quality impairment.

Meta-Analyses of P Cycling or Lack Thereof

Global and regional databases of soil properties, land use, and even field management are now readily available (e.g., Homer et al., 2015; International Plant Nutrition Institute, 2012; Nachtergaele et al., 2009) and are being used to inform predictive and decision-making models, including for agricultural land-use planning (Alexander et al., 2008; Gassman et al., 2007; Radcliffe et al., 2009). When coupled with census survey information, fertilizer sales, and crop and livestock commodity statistics, nutrient budgets can be gleaned at field, farm, watershed, and regional scales (Murrell et al., 2015).

Nearly 20 yr ago, Lander et al. (1998) analyzed budgets of nutrients available in livestock manure relative to crop growth requirements on a county basis across the United States. This provided valuable insight and early warnings of nutrient imbalances that were occurring within productive, yet spatially disconnected livestock and crop production systems (Lanyon, 2005; Maguire et al., 2005). When applied to landscape data, these types of budgets have been used to produce widely used risk vulnerability maps for nutrient runoff and leaching from agricultural lands receiving manures, helping to target nutrient management and conservation programs (Kellogg, 2001).

More recently, MacDonald et al. (2011) expanded the assessment of nutrient use and transfers to a global scale to highlight regions where nutrient inputs to farming systems exceeded output in produce. Their findings offered insight into the role of shifting diets and national nutrient management strategies in P hotspots, as well as disparities in regions where new agricultural development approaches are badly needed. Haygarth et al. (2014) and Powers et al. (2016) used temporal patterns in P accumulation and drawdown in major watersheds of the globe to highlight the role of management legacies in watershed outcomes. Jarvie et al. (2015) integrated spatial distributions of P excreted in livestock manure, P contributions to wastewater from the human populations, and inorganic fertilizer used in the United States, illustrating the pivotal role of P in the food–energy–water nexus. All these meta-analyses help uncover disconnects and imbalances in P cycles, revealing weak links and societal inefficiencies in P use within agricultural systems over broad spatial and temporal scales. In turn, these types of meta-analyses have afforded novel insight into the global connectedness and dependencies of P transfers, demanding comprehensive strategies to reconnect broken cycles.

Addressing the P Paradox within the Realities and Nuances of Agricultural Management

Problems can arise when meta-analyses are interpreted to recommend changes in production practices, in part because global and regional datasets mask or ignore local nuances that influence viable farm-scale operations. At global scales, recommendations derived from inferred resource flows become fundamentally disconnected from the day-to-day realities of farm management. Equally important, variations in local farm operations and practices are often unaccounted for or inadvertently minimized. Recommendations based on "single-issue" rationales, such as P security considerations, fail to consider other, much wider, social, environmental, economic, and energy-related implications.

A recent assessment by Sattari et al. (2016), for instance, drew on global P budgeting combined with continental modeling of soil P cycling to highlight the long-term outcome of using the world's grasslands to meet growing demands for livestock production: declining fertility. Such outcomes are valuable to understand, and they follow on disparities identified in other global assessments of P budgets (e.g., MacDonald et al., 2011). In this example, however, the meta-analysis centered on testing long-term forage production strategies that overcome limits to plant available P in soil, concluding that a fourfold increase in P inputs to the world's grasslands is required (Sattari et al., 2016).

We question the value of proposing a fourfold increase in P inputs to the world's grasslands without consideration of broader implications. Even if intended as a heuristic stimulant, solutions that are derived from univariate calculations of resource constraints on simplified production systems and applied at a planetary level lack academic traction in overlooking the myriad of real-world interactions and implications of their implementation. Simply put, what would be the implication to global P resource security if this increase in P application were met, at least in part, by inorganic P fertilizers?

Addressing these estimated P imbalances in the world's grasslands would also need to overcome well-documented challenges, from practical issues of fertilizer distribution networks and application technologies to social barriers of subsistence producers in the developing world. Projected increases in global demand for meat and dairy products will undoubtedly require integrated strategies combining grain and grassland forages. Moreover, plant uptake of P is limited by interaction with other factors, such as lack of water or soil physical properties. There also needs to be recognition of the collateral impact that increasing P application to unfertilized grasslands would have on water quality (Li et al., 2015; Sharpley et al., 2013).

Our concern is the obvious disconnect between interpretations and recommendations arising from global databases and local conditions, including the realities of farming practice and profitability. Actionable proposals will only come from bridging the disconnect between the macro-need for better P resource management at the regional and national scale with micro-implementation of P management at the farm scale. Acknowledgment and realization of local, practical nuances need to be taken into account in both the literature and science before researchers can connect problems with realistic solutions.

Suggestions that perennial biofuel crops could be grown on landscapes vulnerable to surface runoff or leaching, such as in parts of the Upper Mississippi River and Great Lakes basins, with major grain production moving to less vulnerable lands, are theoretically sound and well-intended (Porter et al., 2015; Thomas et al., 2014). However, agricultural infrastructure would need to change dramatically, which is unlikely in the short term and with current voluntary approaches. Further, shifts in agricultural production away from some of the most productive soils in the United States (the Upper Mississippi River basin and Great Lakes) to protect water quality are unrealistic, given that large-scale production in these areas provides economies of scale needed to maximize efficient food and biofuel production, as well as resource use and management (Hanserud et al., 2016; Nesme and Withers, 2016). The reality is that fragmenting and moving grain production to less productive soils will likely reduce yields and could even undermine national food security. Moreover, this would simply shift water-quality impairment elsewhere (e.g., externalizing the costs of water-quality degradation from the Gulf of Mexico, Florida's inland and coastal waters, or Great Lakes, to other areas, such as Central and South America).

A decade ago, Lanyon (2005) clearly noted that the driving forces behind the spatial separation of livestock, grain, and food production were not a direct result of agricultural management or fertilizer requirements but a consequence of strategic planning within production systems. An existing transport infrastructure to quickly and cheaply move fertilizer, feed, and food from field to fork was a major driver. Also, increasing cost efficiency was linked to an increase in production size and intensity, as well as a desire to stimulate faltering rural economies in many areas. These production systems reflect the consequences of a wide range of agricultural, economic, and regulatory programs and policies (Lanyon, 1992).

Moving nearly 25 yr on from Lanyon's original work (Lanyon, 1992), we still face a lack of spatial connectedness among specialized agricultural systems. These disconnects reinforce the paradigm that there are regions with too much or too little P (as commercial inorganic fertilizer and/or manure), but few that are "just right" (Foley et al., 2011). Thus, the fact that P imbalances are driven by the beneficial economics of existing transport infrastructure and production scale must be considered if we are to realistically address systemic nutrient imbalances highlighted by recent P-resource meta-analyses.

Returning P in manures to distant row crop systems, where grain production for animal feed is optimized with mineral fertilizer sources, is essential to closing P cycles in animal production but faces massive barriers under current economic and technological models. The energy costs for transporting and recycling P from most types of raw manure back to areas of grain production are prohibitively high (Kleinman et al., 2012), and this continues to be the major practical constraint to closing the P cycle at regional, national, and global scales (Sharpley and Jarvie, 2012). For instance, Metson et al. (2016) estimated recyclable manure P would need to travel nearly 200 miles to meet the largest demand in and around the US Corn Belt (where 50% of US corn P demand is located). Although poultry manure might be transported 250 miles, other manures (e.g., dairy and pig slurries, which are at least 90% water) cannot be moved as far without some prior solid–liquid separation followed by value-added steps such as composting, recovery of P as struvite, or co-mixing with other by-products (Oliveira et al., 2016; Oshita et al., 2015).

Manure has historically been bought or regulated for nitrogen, with P being an added bonus, which has led to many of the water-quality issues we now face. However, where P-based recommendations for manure application are in place, applied amounts are substantially reduced and importing manure becomes much less cost-effective than purchasing mineral fertilizer. Further, manure application timing is much more limited and critical for annual cropping systems than for perennial forage systems and can involve the additional expense of manure storage. Thus, any manure handling or treatment to facilitate large-scale transportation adds an expense to the end product that needs to be absorbed somewhere.

Discussion

Given the profound disparities in scale, there is a risk that P-resource meta-analyses that utilize national, regional, and global datasets can overlook local realities of agricultural management, especially when interpretations are made from data generated by another model or predictive assessment. There is also a risk that overlooking local social, economic, environmental realities and constraints that farmers face on a day-to-day basis undermines trust and dialogue between the agricultural research community, extension specialists, farming communities, and agricultural stakeholders.

Without a full understanding of the realities and nuances of agricultural management, we may also be misled as to the root cause of agricultural management change. During deliberations between the dairy industry and regulators in Ireland, for example, declining farm-gate P balances were seen as an indicator of progress in nutrient management (Ruane et al., 2013). The reality, however, was that on-farm P surpluses dropped due to a downturn in dairy prices, as much as from any real changes in fertilizer and feed use (Mihailescu et al., 2015). Similarly, Richards et al. (2002) concluded that years of education and extension activities in the United States resulted in a decrease in nutrient use as fertilizer (17–22%) and manure (34%) in the Lake Erie watershed during the 1980s. However, an even greater decline in fertilizer P use occurred between 2005 and 2008 (33%) when P fertilizers tripled in price (Jarvie et al., 2015).

Blanket recommendations for changes in agricultural policy and practice based on P-resource meta-analyses are unlikely to result in improved efficiencies in P use, or water-quality improvement, unless the realities and nuances of local agricultural production systems are taken into account. The wisdom or beneficial outcomes of changes in P management coupled with adoption of appropriate conservation measures are beyond question. Nonetheless, the real challenges of enacting such changes should not be diminished. Having access to "big data" without a basic or first-hand knowledge of the reality of the underlying systems could lead to erroneous or misleading interpretations and conclusions.

Clearly, the use of "big data" in meta-analyses of P resources can provide invaluable insights into global P flows and identify disconnects in P cycles. Agricultural and environmental researchers have an opportunity to provide practical, science-based solutions to restore or reconnect the fragmented P cycle. As an informed research community, we have a clear duty to work together to ensure that developing management and conservation strategies acknowledge the realities of farm operations, along with economic and stewardship decisions. Consideration of these daily decisions that drive farmer behavior is critical to enacting fundamental and positive changes in sustainable food production and in land and water management.

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