New investments in phosphorus research and training are paramount for Brazilian long-term environmental and food security

Rasera Raniro, Henrique; Papera, Jéssica; Urbano José, Lucas; Valença, Rodrigo Maia; Sergio Pavinato, Paulo ; Hermann, Ludwig; Santner, Jakob

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PERSPECTIVE

New investments in phosphorus research and training are paramount for Brazilian long-term environmental and food security

Henrique Rasera Raniro[1] · Jéssica Papera[2,3] · Lucas Urbano José[4] · Rodrigo Maia Valença[5] · Paulo Sergio Pavinato[6] · Ludwig Hermann[7] · Jakob Santner[1,8]

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Abstract
Brazil is an agricultural giant that plays a crucial role in the Global Phosphorus Challenge (GPC), and whose highly weathered soils are currently dependent on phosphorus (P) fertilizers derived from phosphate rock, a dwindling and critical resource. Brazil imports > 50% of its P fertilizers and P recovery from waste is not yet explored in the country, making it vulnerable to market instabilities, phosphate rock availability, and geopolitical conflicts. To make matters worse, Brazilian research budget has been shrinking for 7 years straight, hindering scientific efforts and causing significant 'brain drain', further undermining the country's capacity to tackle this critical problem. However, an opportunity comes with the new Brazilian Federal government (starting January 2023), which promises to make significant investments in science and higher education. We call for all stakeholders to seize this important moment and timely collaborate in creating multidisciplinary P-related projects, taking advantage of the soon-to-be available resources to develop knowledge, technologies, and training networks to shape a new generation of experts in P management in the tropics. We are confident that through agriculture intensification, intelligent use of resources, new legislation and governance, Brazil will stride towards sustainable food production, bringing immediate value to Brazil and the world by protecting the Amazon forest and advancing to overcome the GPC.

Keywords Brazil · Investments · Phosphorus · Research · Sustainability · Training

✉ Henrique Rasera Raniro
henrique.rasera-raniro@boku.ac.at

1 Institute of Agronomy, University of Natural Resources and Life Sciences, Vienna, Konrad-Lorenz-Straße 24, 3430 Tulln an Der Donau, Austria

2 European Centre of Excellence for Sustainable Water Technology, Wetsus, Oostergoweg 9, 8911 MA Leeuwarden, The Netherlands

3 Department of Biotechnology, Delft University of Technology, Van Der Maasweg 9, 2629 HZ Delft, The Netherlands

4 Department of Physics, Chemistry and Pharmacy, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark

5 Department of Chemistry and Bioscience, Aalborg University, Fredrik Bajers Vej 7H, 9220 Aalborg, Denmark

6 Department of Soil Science, Luiz de Queiroz College of Agriculture, University of São Paulo, Av. Pádua Dias 11, Piracicaba, SP 13418-260, Brazil

7 Proman Management GmbH, Weingartenstraße 92, 2214 Auersthal, Austria

8 Institute for Plant Nutrition, Justus Liebig University Gießen, Heinrich-Buff-Ring 26-32, 35392 Gießen, Germany

1 The Brazilian phosphorus scene

Phosphorus (P) is an essential element for crop production and is naturally scarce in the highly weathered tropical soils predominant in Brazil. With low bioavailable P concentrations, these soils benefit considerably from P fertilization, a practice that is rather inefficient (often only ~ 30% of the applied P is taken up by crops), mostly due to P fixation on the abundant soil Fe/Al oxyhydroxides (Roy et al. 2016). As a result, P has been over-applied for decades across the country, resulting in a P surplus in many agricultural areas, known as 'legacy phosphorus' (Gatiboni et al. 2020). Unfortunately, this accumulated P exhibits low bioavailability, which maintains the need for P additions into the fields and further increases this P pool. Legacy P in Brazilian soils was estimated to grow from ~ 33 Tg in 2016 to ~ 106 Tg by 2050 (Withers et al. 2018), roughly valued at US$165 billion at the current P fertilizer price.

To make matters worse, conventional P fertilizers are produced through the acidification of phosphate rock (PR), a finite material that is rapidly decreasing in quality and is threatened to be depleted in the upcoming centuries, affecting fertilizer prices (Cordell et al. 2009). In Brazil, more than 50% of P fertilizers used each year are imported, and while P recycling from secondary resources such as livestock manure, urban and industrial waste, and agriculture residues could contribute to supply up to 20% of crop demand by 2050 (Withers et al. 2018), the technology and infrastructure for P recycling is almost non-existent in the country.

Meanwhile, other nations are already exploring P recycling to capitalize on these valuable and globally limited resources, while most of the waste in Brazil is still discarded in landfills or directly into the environment, many times without proper treatment (Borges et al. 2022). Apart from squandering an important resource, negligent P use and disposal has been linked to several environmental damages, such as the eutrophication and acidification of key water bodies across the country, a growing concern that results in considerable reduction of water quality (Mekonnen and Hoekstra 2017, Raulino et al 2022, Cotoviz Jr et al. 2022, Ogura et al 2022,), ultimately leading to biodiversity losses. Furthermore, P overapplication under intense soil erosion and degradation scenarios can lead to higher P losses and lower efficiency of P fertilization (Soltangheisi et al 2019), further compromising the sustainability of Brazilian agroecosystems.

This unsustainable, linear P utilization poses multiple challenges for the Brazilian environmental and agri-food sectors. Firstly, conventional P fertilizers present low efficiency, are non-renewable, and highly affected by market price fluctuations (Garske and Ekardt 2021). Secondly, approximately 72% of the world's PR reserves are found in Morocco and Western Sahara (controlled by Morocco), and while the USA, Russia, and China own considerable PR resources, their exportation is currently very limited (USGS 2022). Besides the critical distribution of PR, international geopolitical tensions can generate market instability, which, associated with an increased reliance in Brazilian PR imports, could ultimately endanger national agriculture and food supply. Thirdly, the extensive nature of national agriculture incentivizes the incorporation of new agricultural land and the exploration of valuable natural resources that could otherwise be preserved, instead of taking advantage of the legacy P already existent in the fields (Pavinato et al. 2020).

Studies addressing the Brazilian soil legacy P were recently published by Pavinato et al. (2020) and Zou et al. (2022), who considered its exploration vital to create more P efficient systems. Marin et al. (2022) showcased the benefits of protecting the Amazon Rainforest through agriculture intensification, that is, increasing the productivity of existing arable land through efficient management and sustainable use of resources, while reducing the necessity for clearing new areas for farming. Key benefits from this practice would be biodiversity preservation, regulation of precipitation patterns in the country and beyond, deceleration of climate change through reduced greenhouse gas emissions due to lower deforestation rates and soil tillage etc., all of which are in the national and global best interest. Relative to P, agricultural intensification can be a great tool to better use the Brazilian soil legacy P and reduce overall P application rates in the country.

Furthermore, Brazil plays a critical role in the Global Phosphorus Challenge (GPC; Fig. 1), which can be understood as the international endeavors to study and comprehend the P cycle in the environment, developing strategies to increase P use efficiency and (re)cycling, and reducing the impending threat of PR depletion. Brazil's importance lies in its population size, the global relevance of its agricultural production, being the 3rd largest consumer of phosphate worldwide (FAOSTAT 2019), and its unique environmental characteristics. This presses for investments in P-related research and, as importantly, specific professional training, aiming to foster a new generation of specialists in P management under tropical conditions who will work to tackle the underlying P problems for the national and global benefit.

2 Budget cuts and brain drain

Given the discussed scenario, it is extremely important that investments in education and research are directed towards this sector in Brazil. However, the federal budget for universities and higher education has been steadily shrinking for 7 years straight, going from US$3.4 billion in 2015 to US$1.9 billion in 2021. The budget for the Brazilian National Council for Scientific and Technological Development (CNPq), for example, dropped from around US$600 million in 2016 to US$218 million in 2021, while governmental contingencies to the Coordination for the Improvement of Higher Education Personnel (Capes) delayed the payment of over 200 thousand postgraduate stipends in December 2022, making it extremely hard to pursue research in the country.

In the meantime, several countries worldwide are supporting initiatives to address the GPC, investing large research budgets, in the range of several hundred million US dollars. In North Carolina (USA), for instance, an intended total of US$25 million is currently being invested into building the Science and Technologies for Phosphorus Sustainability center (STEPS), a research facility dedicated only to the study of this critical element. This clearly shows the importance attributed to P sustainability in such countries, their willingness to invest and their concerns for researching solutions for the upcoming problems that threaten the stability of their environmental and agricultural landscapes.

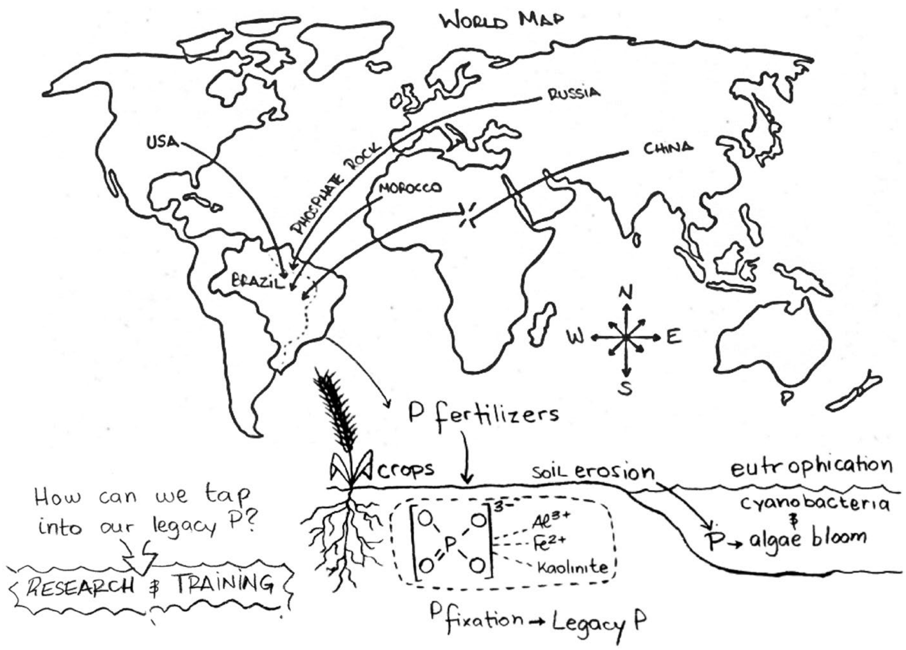

Fig. 1 Sketch of the Brazilian phosphorus situation in the context of the Global Phosphorus Challenge

This leads to yet another concerning scenario for Brazilian P research, the "brain drain," that is, the exodus of skilled workers (in this case postgraduate students and researchers) from the country, led by (among other reasons) the lack of funding opportunities in their field and better prospects to pursue their research elsewhere. This new generation of Brazilian researchers is then trained abroad and develops research that is usually unrelated to the Brazilian context. After their training, many end up not returning to the country due to the lack of professional perspectives. On top of that, some who never left are simply giving up their research careers altogether for better-paying industry jobs with greater opportunities, converting public money invested in their training into private profit.

3 Research and training as safeguard to national security

In 2018, Brazil hosted the 6th Sustainable Phosphorus Summit—a collaboration between academia, industry, and government. For the first time, this aimed to put a research and governance spotlight on managing P in tropical conditions, highlighting significant research gaps. We are confident that there is a clear way forward through P research and training in the fields of agriculture, environment and ecology, technology, waste management, and social studies. Together, the achievements from each sector may complement each other, potentially developing novel P recovery and recycling technologies, highly efficient new-generation fertilizers, management strategies to enhance P use in agriculture, as well as a new framework for P governance and legislation, a crucial and yet overlooked topic not only in Brazil, but also globally (Rosemarin and Ekane 2016).

To fill in these research, training and governance gaps, multiple frameworks can be employed to build a foundation for our understanding of the current conjecture for P in Brazil. The Triple Bottom Line framework, for instance, could aid in the evaluation of the relationship between the economic, social, and environmental impacts of novel P management strategies, allowing for an optimization in all three dimensions (Loviscek 2021). Likewise, the use of other frameworks such as Planetary Boundaries (Leal et al. 2019), Sustainability Development Goals (Langhans et al. 2022), Life Cycle Assessment (Roque et al. 2020), among others, have been previously explored for P products and strategies and could be considered to provide directions on how to operationalize a sustainable phosphorus future for Brazil.

The proposed actions could bring immediate value to the Brazilian agriculture, environment, commercial balance (by reducing imports), and security, benefitting farmers and society. Failing to train the next generation of P specialists in due time will very likely render Brazil vulnerable to increasing fertilizer prices, PR scarcity, international willingness to trade, and geopolitical tensions, keeping the country further away from being efficient in the management of this finite and critical element. Should this alarming shortage of trained professionals persist, Brazilian food, energy, and fiber production may be severely jeopardized in the upcoming decades.

To cope with these uncertainties, Brazil needs governmental financial support and investments, as well as cooperation between the academic and private sectors to foster national P research and training networks, contributing to a new generation of scientists, engineers, policy makers, professors, and other relevant professions in all P-related fields, as has been suggested for the European Union, for example, by Reitzel et al. (2019). Brazil must begin to upskill its workers immediately to ensure long-term stability in the Brazilian agroecosystems and food supply and to stride swiftly towards a resolution to the GPC.

In January 2023, Brazil transitioned to a new Federal government, which promises, as translated by the authors: 'to restructure the Basic Funding System through the full compensation of the National Fund for Scientific and Technological Development (FNDCT)…' and '…to promote the institutional strengthening of the Capes and the CNPq, as well as …of the Funding Authority for Studies and Projects (Finep) and the Brazilian Development Bank (BNDES)…' (Brazilian Worker's Party 2020). It is expected, therefore, that the new government fulfills its duties by reinvesting in quality science and training moving forward. At the same time, we call for the mobilization of all stakeholders to collaborate in structuring well-rounded, multidisciplinary, judicious, objective, and realistic P-related projects, calls and initiatives in the attempt to promote fast advancements to tackle the GPC and safeguard Brazil against the uncertainties that will surely be upon it in the near future.

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Author contributions HRR wrote the main manuscrip text and drew Fig. 1.All authors provided substantial feedback and insights on the main text, providing corrections, reviews and proof reading.

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Declarations

Competing interests The authors declare no competing interests.

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