Preface

Sustainable phosphorus management: The Indian scenario in a global context

This issue presents a special section on sustainable phosphorus management which impacts India's agriculture, fisheries and animal production systems along with P-flux to major Indian rivers and air–sea deposition to a portion of the Indian Ocean. Phosphorus is an essential nutrient, an irreplaceable element and a building block of all life forms. It controls net primary productivity and species composition in terrestrial and aquatic ecosystems. However, P cycle is one of the most anthropogenically perturbed biogeochemical cycles. In spite of being the 13th most abundant element on the Earth's crust, it is a highly reactive element that moves from sedimentary rock through the agricultural and animal production systems and ultimately dissipates in the sea causing eutrophication and biodiversity changes, from where recovery of P is highly uneconomical at present. Globally, phosphorus needs are currently met from geological sedimentary rock formations available in select areas of the world. These are finite resources that will not last forever, even though estimates vary on whether they will exhaust in half a century or a few centuries, depending on whether we take into account currently accessible sources of P in the world or the total resources that exist. Rock phosphate mining in 2011 amounted to 191 Mt, corresponding to 25 Tg P yr^{-1}. Overall, 82% of the mined P is required for fertilizers, 7% as a nutrient in feedstock and 11% for pharmaceuticals, detergents, fire crackers and other and industries. The future demand for P is anticipated to increase at 2.3% p.a. largely due to increasing food demand in the developing world, a shift towards meat-based diet (which consumes more P than vegetarian diet) and increasing biofuel production. The future supply will depend on declining stocks, quality deterioration of rock-phosphates and increase in the cost of P extraction apart from geopolitical factors and the potential for monopoly pricing. Agriculture and food security in the developing world would be worst hit by the availability and/or affordability of P inputs.

India also suffers from the lack of geological reserves of high-grade P and is dependent on imports to meet up to 90% of its domestic P requirement. The need to address P deficiency in Indian soils and increase agricultural production, enhanced the consumption of P fertilizer in India from 0.053 Tg (1960–61) to 7.3 Tg (2009–2010) and is expected to reach 14.0 Tg by 2030–2031. The country witnessed steep increases in the prices of P fertilizers in the recent years and this scenario is not likely to change dramatically in the future and efficient usage of P to minimize wastage/loss remains the only option.

In this background, the Society for Conservation of Nature, a registered NGO of scientists had earlier addressed issues of sustainable management of reactive nitrogen under the 'Indian Nitrogen Group' (ING-SCON) brought out a special section of *Current Science* (volume 94, issue 11, 2008). Now, a critical analysis of the sustainable P management scenario for India and the emerging future challenges as presented in this special section. As would be obvious from the 12 articles in this special section, our knowledge of the P-cycle in the Indian context is less understood and at best tentative due to the huge diversity of soil types, nutrient demands, ecological conditions and developmental challenges of the country. India will have an increasingly important role to play among the countries of the South and South-East Asia, which share not only common international waters but also related concerns on land–ocean connections apart from the common concern to continue producing enough food through their agricultural system to feed the growing population.

In order to encourage and ensure sustainability of P use, it is essential to introduce need-/evidence-/research-based policies of P management based on an integrated understanding of the complete biogeochemical cycle of P in India. The various options include: (i) Active recycling of P locked in organic residues and enhanced release of unavailable-P fractions. (ii) Development of P-efficient crop cultivars. (iii) Development of microbial/mycorrhizal P solubilization in the rhizosphere. (iv) Recycling P from within the human food chain for fertilizer. (v) Recovering P lost as pollutant from sewage, wastes and water bodies.

In the inaugural article of the section, Scholz *et al.* (**page 1237**) describe Global TraPs (2010–2015) project, a transdisciplinary venture that is expected to bring together 'practice' (producers, traders, users of phosphorus, sewage plant operators, recycling companies, public agencies, NGOs, etc.) along with those facilitating their efforts (such as policy makers, development organizations) and 'science' (researchers from various disciplines with an interest in phosphorus) to work towards a common aim of ensuring future P usage to a sustainable basis. Mazumdar and Banerjee (**page 1247**) describe phosphogenesis of an early Cambrian phosphorite deposit in the Krol belt of lesser Himalaya in terms of mineralogy and petrography. Based on the available early Cambrian oceanographic models, it was suggested that a repeated influx of P and organic-C rich water on to the shallow platform resulted in the precipitation of amorphous calcium phosphate from the shallow water column overlying the sediment water interface and subsequently modified to microsphorite (micritic phosphorite). Geochemical evidences support marine phosphate source possibly via upwelling/transgression of phosphate-rich anoxic water over the shallow depositional milieu during early Cambrian.

In view of the dependence on large-scale import of phosphorus, Subba Rao *et al.* (**pages 1253**) studied whether lack of phosphorus would affect the future food security of India. Using P-fertilizer requirement calculations, they showed that 2.92 million tonne of P_2O_5 was removed through crop uptake (in 2000–2001), whereas additions due to fertilizers, manures and deposition were 5.24 million tonne, thus the overall P balance remains positive. In addition to ensuring adequate P additions, techniques need to be developed to harness the otherwise fixed or unavailable P in soil so as to reduce the P addition. In the following article, Sanyal *et al.* (**page 1262**) take stock of the available information on the P dynamics in soil, P management in important cropping systems for enhancing its use efficiency, soil testing for plant-available P to prescribe fertilizer P application and losses of P through erosion and runoff.

Plants possess a number of adaptive mechanisms to cope with P stress leading to changes at morphological, physiological, biochemical and molecular levels. Elanchezhian *et al.* (**page 1271**) in their article collate a comprehensive understanding of these adaptive responses and engineer them to improve the efficiency of uptake, partitioning and utilization of P, together with other agronomic approaches that would result in meeting the P challenge in agriculture sustainably. Adhya *et al.* (**page 1280**) reiterate the role of microorganisms in mobilizing inorganic and organic P in the soil and the rhizosphere. They suggest that increasing availability of soil P through microbial inoculation will necessitate identification of the most appropriate strains, preparation of effective formulations, and introduction of efficient agronomic managements to ensure delivery and survival of inoculants and associated improved P efficiency. In the following article, Bagyaraj *et al.* (**page 1288**) discuss the role of arbuscular mycorrhizal (AM) fungi in the uptake of P from soil solution. It is now proved beyond doubt that AM fungi greatly enhance plant growth that is mainly attributed to uptake of diffusion limited nutrients such as P, Zn, Cu, etc. from soil. Field studies have shown that inoculation with efficient AM fungi not only increases growth and yield of crop plants but also reduces the application of phosphatic fertilizer by nearly 50%. Further, low grade rock phosphates available in India can be used with AM fungi as a potential source of P for crop plants.

P entrapped in soil complex is often driven by erosion and ends up in riverine transport, ultimately reaching the ocean. Ramesh *et al.* (**page 1294**) examined the major forcing functions that affect the riverine composition of phosphorus (P) in the Indian context. The flow of dissolved inorganic phosphorus (DIP) and particulate inorganic phosphorus (PIP) to the coastal ocean from Indian rivers is estimated to be about 190×10^3 tonnes yr^{-1} and $1,367 \times 10^3$ tonnes yr^{-1} respectively, which is more than twice the concentration for other rivers in the world. Such increased nutrient input into the riverine system reflects the imbalances and alterations in terrestrial sources emphasizing the need to monitor the quantity and quality of nutrient input to the rivers. Ocean being the ultimate sink of all the nutrients including P carried through the sediments, Srinivas and Sarin (**page 1300**) summarize sources and atmospheric pathway of phosphorous to the surface ocean as a case study from the Northern Indian Ocean. Estimates of P-deposition to the Northern Indian Ocean were found to be comparable to the deposition in other oceanic regions and were also consistent with the model-based projections for the Northern Indian Ocean. These results reiterate need for quantification of intra-system P fluxes leading to release of P to the outer ocean. In the following article, Vass *et al.* (**page 1306**) indicate that in India, harnessing water productivity through fishery and aquaculture is a major food production activity. However, our current knowledge of phosphorus dynamics in diverse aquatic ecosystems is very fragmentary. In fish/prawn culture using both inorganic and organic source of P, it was observed that maximum P gets loaded into pond sediments and about 60% of total P lost was primarily through discharge water (everyday water exchange – 56% and pond drainage – 4.5%).

Prasad *et al.* (**page 1315**) in their article indicate that phytate in the animal feed of plant origin and the inability or limited ability of monogastric animals such as poultry and pigs to degrade phytate in gut results in the excretion of large amounts of P in the excreta causing eutrophication. Desired dietary level of P in ruminant and monogastric animals and improving gut bio-availability using better bio-available inorganic sources and balancing of different micronutrients and phytase supplementation needs intense research attention to enhance P-utilization for better animal production and environmental sustainability. In the final article, Kundu *et al.* (**page 1320**) while describing eutrophication of surface water in India emanating from the use of detergents, indicate that the current estimated annual consumption of phosphate-containing laundry detergents in India is about 2.88 million tonnes and the total outflow of P is estimated to be 146 thousand tonnes per year. With increase in population and associated urbanization in India total out flow of P to the sewage system will also increase remarkably in near future. Currently, with a population of ~1.3 billion, India is estimated to release 0.38–1.02 Tg P per annum to the environment. Thus, there is a need to complete the P biogeochemical cycle through policies and practices for effective recovery and recycling of phosphorus-containing wastes (including human wastes) into agriculture to enhance food production.

There is undeniable resource, economic and environmental justification for society to reduce its reliance on mined (fertilizer) P and increase its efficiency of use. Heavy reliance on imported inorganic fertilizers to balance crop P offtake in countries such as India is perpetuating an oversupply of P to a very inefficient food chain. This will only get progressively larger as crop yields are increased to meet the food and fuel demands of an expanding population. While the articles in the special section of this issue are by no means a comprehensive picture of the Indian scenario, they are at best indicative of the issue to draw attention of the planners to this critical aspect of nutrient use. It is expected that such articles published by *Current Science*, a uniquely placed interdisciplinary forum, will activate appropriate research and policy initiative that would better voluntary alliances among scientists, policy makers, industry and other stakeholders unhindered by disciplinary or organizational boundaries.

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