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Eutrophication: can nanophosphorous control this menace? A preview

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ABSTRACT

Eutrophication is a threat to quality of surface and ground water bodies (SWB) and to bio-diversity of the aquatic eco-system. Excess application of P is one of the causes of its accumulation in SWB. Phosphorus buffering also contributes to eutrophication and remains a major problem years after the release of P is brought under control. The addition of small amount of P or, nano-P can remove excess P from soils, provided the solution-P is maintained in such a manner that productivity is sustained. In such endeavours, P must be applied in amount exact to the crop requirement. Nano-P application can deal with twin contradictions – low solubility and excess application. Thereby it reduces P build ups in soils, reduce its load in SWB, and checks contamination in drinking water. However, ecological cautions of use of nano-P must not be ignored. Many P fertilizers contain heavy metals, which may be eliminated by nano-P application. To comprehend P dynamics, land and SWB system must be treated holistically, and sub-divided into components, each with realistic independent system-variables coupled with the processes. In nano-P ventures high resolution imaging not only provides evidence of the changes that occur in various phases, but is also an indispensable tool to understand how P dynamics operate.

Keywords: Ground water body, nano-P, nanoscience, phosphorus, surface water body and zeophonics

1. The problem and the processes of P accumulation in surface water-bodies

Every night earth is between you and the sun, and every morning view between you and aquatic life in surface water-bodies (SWB) is blocked by eutrophication! This menace is a threat to quality of surface and ground waters and very survival of the aquatic eco-system, and that snaps dynamics of "human ↔ landscape ↔ aquatic" life support system. Eutrophication refers to the blooms on SWB, which are commonly surrounded by farmlands (including dairy) or human settlements. It happens as a consequence of phosphorus movement along with run-off water from land and its accumulation in SWB. The annual surface runoff is estimated between 0.01 and 3.00 kg P ha^{-1} and annual erosion of P-containing soil minerals is between 0.1 and 10 kg ha^{-1} (Brady and Weil, 2002). One of the causes of P accumulation in SWB is its dumping on agricultural lands as a fertilizer, and dairy affluent. Both are non-point sources of pollution, and thereby only way to control them is to manage farming in environmentally sustainable way. Phosphorus has a very low solubility in soils, and the range of P availability is $<10^{-8}$ M in some very poor tropical soils, in the order of 10^{-6} M in temperate soils, 10^{-5} M in many soils of moderate P status, and it can exceed 10^{-4} M in some well supplied soils. Phosphorus concentration of 10^{-5} M corresponds to 0.3 mg P L^{-1} in the soil solution (Russell, 1973). To maintain the desired level of P in soil solution; a key to productivity, excess amounts of P is added to soils, and the phenomenon continues for years. For example, in a long-term experiment in an acid soil (Alfisols) at Palampur (Himachal Pradesh), Sharma *et al.* (2006) have been applying 50 kg P ha^{-1} per annum to rice-wheat cropping system that maintains available P at 47.5 kg ha^{-1}, but P uptake was clogged to 31.7 kg ha^{-1} $year^{-1}$ implying a build-up of 18.3 kg P ha^{-1} $year^{-1}$. Incidentally this treatment was most economic. In a groundnut-wheat-sorghum cropping system at Junagarh (Gujarat), Hadvani *et al.* (2006) observed that no or small P addition removed P from soils, but high doses caused its build-ups (Table 1). It could be discerned from these experiments and also many other similar experiments conducted world over that addition of small amount of phosphorus can remove excess P from soils, provided solution P is maintained in such a manner that productivity is sustained. The challenge is more severe, if soils are alkaline, or calcareous, or acidic, or have significant amounts of P fixing minerals (e.g., kaolin, oxide, interstratified minerals). Can at this stage nanoscience approach deal with the twin contradictions – between low solubility and excess application, and between maintenance of P solubility and its fixation? One would say "yes", because in spite of still being in its infancy, nanoscience promises fresh approach to P management in soils with focus on environmental clean-up and slashing cost of farm production.

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Table 1 : Phosphorus turnover after 25 years of fertilizer experiment in a groundnut-wheat-sorghum cropping system at Junagarh (Gujarat).

Treatment	Initial P status	Nutrient addition	Nutrient removal	Final Pstatus (End of the experiment)
		------------------- kg ha^{-1}	--------------------	
F_1 Control	27.5	0	204	19.4
F_2 FYM	27.5	546	599	23.5
F_3 NP	27.5	1490	591	25.3
F_4 NPK	27.5	1566	778	25.7

Adapted with modification from Hadvani *et al.* (2006)

Processes of eutrophication

Phosphorus in soil solution stays in dynamic equilibrium with phosphate minerals (solid phase P and particulate-P), and solid phase P constitutes > 99 per cent of total P. In surface water-bodies, soil mineral bound P often settles at the bottom, and as these sediments become anoxius, increments of transformation from solid to solution phase rises because of anaerobic conditions that facilitates reduction of Fe^{3+} and Mn^{4+} to Fe^{2+} and Mn^{2+} respectively. The phenomenon; phosphorus buffering is a major contributor to eutrophication and remains a major problem years after the release of P is brought under control. When the dissolved-P concentration of an aquatic system is relatively high, particulate- P will stay attached to suspended sediments and remain relatively unavailable. As algae reduce the concentration of dissolved-P in the water column, particulate- P will move off the sediment and replenish the dissolved-P in the system. Critical levels in water that can trigger algae growth is 20 ppb of dissolved-P, which is - in orders of magnitude - lower than the P concentrations found in soil solution. Just a few decades ago, such low concentrations were below the minimum levels of detection of most laboratories. (Correll, 1998)

2. Nanoscience and nanotechnology

Nanoscience and its applied sphere that is known as nanotechnology have potential to bring the next revolutionary breakthrough in agriculture-biased natural resource management. It has ushered as a new interdisciplinary venture-field by converging science and engineering into agriculture and food systems (Abdul-Kalam, 2007, Lal, 2008). Electron microscopes (EM) are indispensable tools for this nascent discipline. Almost all electron microscopes [Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM), and Atomic Force Microscope (AFM)], and their attachments [e.g., Energy Dispersive Spectroscope (EDS)] are used for soil study. Electron waves in SEM and TEM and laser beam in AFM are used for coalescing micrographs. Since the wavelength of electron under normal circumstances is 1 nm, viewing images of small materials under EMs are grossly termed as nanoscience / nanotechnology. Environmental Protection Agency of US has defined nanotechnology as the understanding and control of matter at dimensions of roughly 1-100 nm, where unique physical properties make novel applications possible (EPA, 2007). By this definition all soil-clays, many chemicals derived from soil organic matter (SOM), and several soil microorganisms fall into this category. Apart from native soil-materials, many new nanotech products are entering into soil system - some of which are used for agricultural production and some others for many other purposes. The advantages with EM are high resolution imaging, high magnification, and great depth of focus. Agricultural research must be kind to nature, and in harmony to the mutually beneficial man-nature relationship. In such endeavors, P must be applied to soils in amount exact to the requirement of crop. If this approach is successful then it would eliminate P build up in soils and as a result in water bodies. Nanoscience exactly aims for it, but ecological cautions must not be over ruled (Mukhopadhyay *et al.*, 2008).

A disturbing fact is that the fertilizer use efficiency is 10-25 percent for phosphorus (<1% for rock phosphate in alkaline calcareous soils). With nano-fertilizers emerging as alternatives to conventional fertilizers, build ups of nutrients in soils and thereby eutrophication and drinking water contamination may be eliminated. In fact, nano-technology has opened up new opportunities to improve nutrient use efficiency and minimize costs of environmental protection (Mukhopadhyay *et al.*, 2008).

Some of the areas, where nanoscience and nanotechnology have found applications for the production of food and protection of environmental quality by keeping the ratio of phosphorus required and phosphorous actually used by the plants/crops near to unity are:

1. Improving efficiency of native and applied phosphorus in soils,

2. Regulation of essential and toxic elements, associated with phosphorous in pedosphere-hydrosphere continuum,
3. Ion transport in soil-plant system, especially in the rhizosphere,
4. Increased endeavor towards precision farming w.r.t. phosphorous.
(Mukhopadhyay *et al.*, 2008).

3. The other side of the environmental concern

Our expanding-ability to synthesize nanoparticles for use in electronic, biomedical, ceramic, pharmaceutical, cosmetic, energy, environmental, catalytic, and similar materials has alarmed concern for these particles role in environmental safety. You can guess the situation from the fact that in 2004, 2000 tons of engineered materials were used, which is expected to increase to 58 000 tons in 2011-2020 (Nowack and Bucheli, 2007). All these materials eventually land on soil. To be useful to the society, nanoscience efforts must adhere to environmental ethos.

4. Zeophonics – the success story of nutrient management weaved by P

Zeoponics; a system founded on the concept of interconnected nature of all life-forms and life-support-forms, relies on recycling and operation of system-components. It opened new vistas in the traditional fields of agriculture and forestry by demonstrating that a system can be made self-supporting, and can supply nutrients to plants for a long time, if a balance is struck between loss and gain of nutrients. The system provides a framework where impetus and response are almost equal. This implies that the first law of thermodynamics can be translated to near implementation level in an open system. This is the only means of survival in the extraterrestrial planets, space stations, and in the Antarctica. It supplies nutrients needed for plants, sorbes gases and converts bio-waste into useful materials. It recycles production-consumption-waste system without contaminating immediate environment. It can be used as a nutrient-controller (for P and micronutrients) or release rate limiter (for N).

Soil minerals, like hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$] are successfully used for this system. Similarly, exchange of NH_4^+ and K^+ are regulated effectively through substituted clinoptilolite (Allen *et al.*, 1995; Ming *et al.*, 1995; Sutter *et al.*, 2002; Sutter *et al.*, 2003). Sutter *et al.* (2003) used TEM images to decipher Fe-, Mn-, and Cu-substituted synthetic hydroxy apatite. Their TEM-EDS images show how core apatite changes when ions of Fe, Mn, or Cu substitute H^+.

To comprehend P dynamics, land and SWB system must be treated holistically, and sub-divided into components, each with realistic independent system-variables coupled with the processes, which tie these system variables. Possible variables that could be considered in model making may be agronomic process that encourage erosion and run-off (e.g., tillage, irrigation practices), soil processes (e.g., preferential flow, texture, structure), and environmental factors (e.g., monsoon rains, climate parameters). Structure and function of every component, their time hierarchy and interactions with the environment must also be taken into account (Karpinets and Greenwood, 2003). [Mukhopadhyay and Brar (2006) and Mukhopadhyay and Datta (2001) discussed some of these aspects, but pertaining to potassium management. There is scope to use concepts for P]. In nano-P ventures high resolution imaging not only provides evidence of the changes that occur in various phases, but also an indispensable tool to understand how dynamic systems operate.

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REFERENCES

Abdul-Kalam, A.P.J. 2007. Innovate to Empower Agriculture and Convergence of Technologies. Address and Interaction with the Students, Faculty Members and Staff of the G.B. Pant University of Agriculture and Technology Pantnagar, Uttarakhand on 11 August 2007 (Website <www. Gbpuat. ac. in>).

Allen, E.R., Ming, D.W., Hossner, L.R., Henninger, D.L., Galindo, C. 1995. Growth and nutrient uptake of wheat in clinoptilolite-phosphate rock substrates. *Agron. J.*, **87** : 1052-59.

Brady, N.C. and Weil, R.R. 2002. *The Nature and Properties of Soils*, 14th Edition. Pearson Education, Inc, Singapore, pp. 603.

Correll, D. L. 1998. The role of phosphorus in the eutrophication of receiving waters: A review. *J. Env. Qual.*, **27** : 261-66.

EPA, 2007. *Nanotechnology White Paper*. U.S. Environmental Protection Agency Report EPA100/B-07/001, Washington DC 20460, USA.

Hadvani, G.J., Golakiya, B.A. and Babaria, N.B. 2006. Sustaining crop yields with organic and inorganic fertilizers under intensive cropping system. *In. Balance Fertilization* *for Sustaining Crop Productivity*, Vol. II International Potash Institute, Horgen, pp. 172-75.

Karpinets, T.V. and Greenwood, D.J. 2003. Potassium dynamics. *In. Handbook of Processes and Modeling in Soil-Plant System*. Haworth Press, New York, pp. 525-60.

Lal, R. 2008. Soils and India's food security. *J. Indian Soc. Soil Sci.*, **56** : 129-38.

Ming, D.W., Barta, D.J., Golden, D.C., Galindo Jr. C. and Henninger, D.L. 1995. Zeoponic plant growth substrates for space applications. *In Natural Zeolites '93: Occurrence, Properties, and Use.* International Committee on Natural Zeolites, New York, pp. 505-15.

Mukhopadhyay, S.S. and Brar, M.S. 2006. Mineralogy and management of soils rich in potassium containing minerals. *Proc. Int. Symposium Balanced Fertilization,* Volume 1. International Potash Institute, Horgen, pp. 95-114.

Mukhopadhyay, S.S. and Datta, S.C. 2001. Potassium availability in relation to mineralogy in the Indo-Gangetic Plains. *In Importance of Potassium in Nutrient Management for Sustainable Crop Production in India.* International Potash Institute, Horgen, pp.33-44.

Mukhopadhyay, S.S., Parshad, V.R. and Gill, I.P.S. 2008. Nanoscience and nano-technology: cracking prodigal farming. *Int. Symp. on Natural Resource Management* held on 19-20 December 2008, Jaipur, India.

Nowack, B. and Buchelib, T.D. 2007. Occurrence, behavior and effects of nanoparticles in the environment. *Environ. Pollution*, **150** : 5-22.

Russell, R.W. 1973. *Soil Conditions and Pl. Growth*, 10th Edition. ELBS, London.

Sharma, S.K., Rana, S.S., Bhargava, M., Sharma, S.K., Sharma, H.L. and Sharma, J.J. 2006. Long-term effect of integrated nutrient management on the productivity and sustainability of rice-wheat cropping system in an acid Alfisols of Himachal Pradesh. *In. Balance Fertilization for Sustaining Crop Productivity*, Vol. II International Potash Institute, Horgen, pp. 161-64.

Sutter, B., Ming, D.W., Clearfield, A. and Hossner, L.R. 2003. Mineralogical and chemical characterization of iron-, manganese-, and copper-containing synthetic hydroxyapatites. *Soil Sci. Soc. Ame. J.*, **67** : 1935-42.

Sutter, B., Wasowicz, T., Howard, T., Hossner, L.R. and Ming, D.W. 2002. Characterization of iron, manganese and copper synthetic hydroxyapatites by electron paramagnetic resonance spectroscopy. *Soil Sci. Soc. Ame. J.*, **66** : 1359-66.