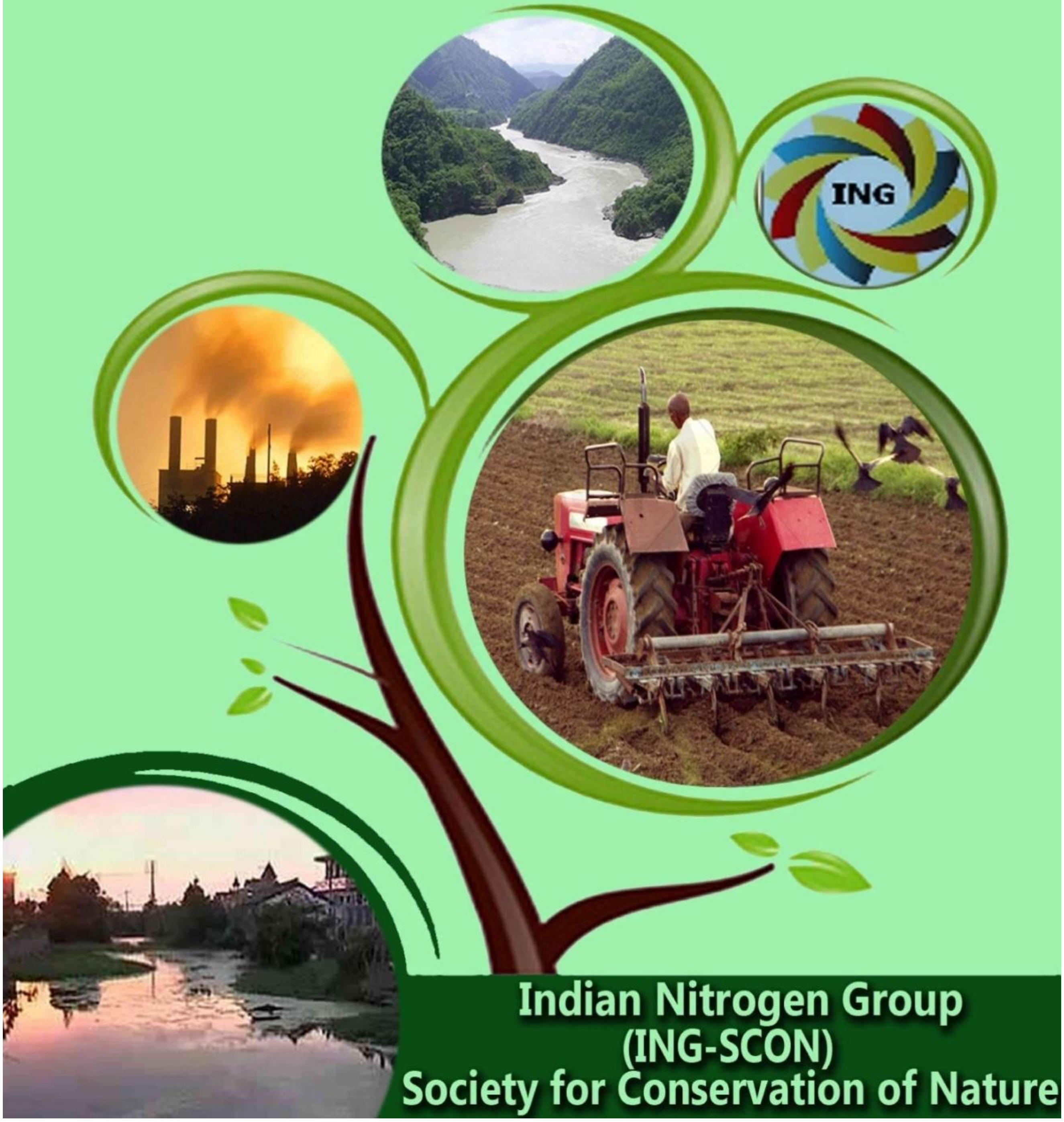
Phosphorus Cycle: Sustainable Management of Resources, Food Security and Environment



Workshop on

Phosphorus Cycle: Sustainable Management of Resources, Food Security and Environment

NASC Complex, New Delhi
18th -19th January, 2013

Proceedings & Recommendations

Convener: Tapan K. Adhya, Co-ordinator, ING-SCON

Organized by
(Indian Nitrogen Group)
Society for Conservation of Nature

Funded by
Ministry of Earth Sciences, Govt. of India

Acknowledgement

ING-SCON has been actively engaged in research and policy aspects of reactive nitrogen from the point of view of agricultural nutrient use efficiency and limiting nitrogen emissions from other sectors to retard climate change. Since the launch of the Global Partnership on Nutrient Management (GPNM) and ING's engagement in the global dialogues as a member of the GPNM, ING has broadened its focus and interest towards other important nutrients such as phosphorus and look at them collectively from a nutrient management perspective. ING's work in the field of nitrogen and phosphorus management contributes both for the scientific and policy discourse in India and wider global debates that are pursued under the auspices of GPNM and the Global Environment Facility supported project Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of Global Nutrient Cycle. The workshop organized by ING with funding from the Indian Ministry of Earth Sciences are ING's contributions to promote effective nutrient management to achieve the twin goals of food security through increased productivity and conservation of natural resources and the environment.

The Organizers

Indian Nitrogen Group

Indian Nitrogen Group (ING) was established as a think-tank and policy forum under the umbrella of the Society for Conservation of Nature (SCON), by bringing together select Indian experts from diverse backgrounds to discuss the issue of N in the Indian environment. The group undertook a series of nationwide consultations with the National Academy of Agricultural Sciences (NAAS) in 2005 and the Department of Biotechnology (DBT), Govt. of India and Indian National Science Academy (INSA) in 2006, with active support from other agencies including the Ministry of Environment and Forests (MoEF), Govt. of India and Council of Scientific and Industrial Research (CSIR). The discussions on Nr and N use efficiency in Indian agriculture led to the adoption of a policy paper entitled "Policy options for efficient N use". A network of researchers and science experts has also been formalized as an outcome of the INSA workshop in 2006. ING has begun to identify gap areas and catalyze research into them. ING came into contact with the International Nitrogen Initiative (INI), to address similar concerns and bring about international coordination. Other recent regional initiatives elsewhere, such as an organization called "Nitrogen in Europe" and the "NitroEuropeIP", a project for integrated European research into the N cycle, highlight the growing concerns related to nitrogen at the national, regional or international level. ING will coordinate with such bodies to harmonize the national regional and international concerns and priorities on reactive N.

The Society for the Conservation

The Society for the Conservation of Nature (PRAKRITI) is a non-profit, non-governmental organization, registered with the Govt. of India under the Societies Registration Act XXI of 1980 on July 22, 1998. The registration no. of the society is 33194. Its registered office is situated at F-4, A Block, NASC Complex, Dev Prakash Shastri Marg, New Delhi 110012, India. It has been actively engaged in promoting research, education and awareness for preserving the environment against onslaught of industrial expansion, intensification of agriculture and adoption of resource intensive life styles. Since its inception, SCON has organized wide spectrum of activities including scientific talks, environmental awareness and community services. The society was established with the following aims and objectives:

- To acquaint the public at large with scientific basis on major environmental problems.

- To suggest better ways of utilization of natural resources like soil, water and air, climate and other genetic resources.

- To initiate dialogue with industry and scientific agencies to utilize biological resources.

- To emphasize particularly the role of women in controlling pollution at the household level and further educating the younger generations about the need to develop a clean environment.

- To collaborate with the international agencies and non-resident Indians to hold seminar/ workshops and publish state of the art report in research/ policy journals as well general publication of public interest.

Funding Agency

Ministry of Earth Sciences, Govt. of India

The Ministry of Earth Sciences (MoES) is mandated to provide the nation with best possible services in forecasting the monsoons and other weather/climate parameters, ocean state, earthquakes, tsunamis and other phenomena related to earth systems through well integrated programmes. The Ministry also deals with science and technology for exploration and exploitation of ocean resources (living and non-living), and play nodal role for Antarctic/Arctic and Southern Ocean research. The Ministry mandate is to look after Atmospheric Sciences, Ocean Science & Technology and Seismology in an integrated manner. The Earth Commission, Ministry of Earth Sciences works in Mission Mode based on Commission structure, is responsible for formulating policies, oversee implementation of policies and programs in mission mode, and ensure the necessary interdisciplinary integration.

Contents

Foreword

Phosphorus is a key chemical element that is essential to life because of its role in numerous key molecules in the 'storage and processing of genetic information', as well as a major component in the "energy currency" of cells as ATP and of the redox generating molecules like NADP. Given this crucial role the pool of biologically available P controls ecosystem productivity including agriculture to a great extent.

Phosphorus plays a critical role in Indian Agriculture. As the proven reserves are of inferior quality, India's import dependence for P is >90%. On Indian scenario, P is consumed to the extent of 7 million tonnes. Most of the P stays in the soil with some gradual movement to the rivers while in some regions, air movement is reported. With its poor use efficiency of approximately 20 per cent, emphasis needs to be placed on solubilization and increased recovery from the soil by root modification, microbial as well as mycorrhizal activities to reduce dependency on exogenous application of phosphatic fertilizers. Other possibilities are improvement in Food Chain Use Efficiency; to recover P from : **a**. human waste i.e urine and faeces; **b**. surface seas. The technologies need to be placed in order for all the possibilities. In other words, we need to move from **P PATHWAY TO P CYCLE.**

The Ministry of Earth Sciences (MoES), Govt. of India, considering their mandate to develop an intricate understanding of the Biogeochemical P Cycle as a step towards developing a land-water-air-ocean continuum, very kindly supported the initiative of holding the workshop on "Phosphorus Cycle: Sustainable Management of Resources, Food Security and Environment".

The two-day deliberations that identified a number of researchable and policy issues need to be implemented by all users including ICAR Institutes/ Agricultural Universities, Ministries of Agriculture, and Fertilizers & Chemicals apart from Ministries of Earth Sciences, and Environment.

YP Abrol
President, ING.SCON

Workshop on 'Phosphorus Cycle: Sustainable Management of Resources, Food Security and Environment'

Preamble

Fertile soils are the key to sustainable crop production for meeting the demands of food, feed and fibre. However, most soils are not sufficiently fertile, requiring periodic but regular amendments with nutrients required by plants. Anthropogenic soil fertilization usually takes the form of adding nitrogen and phosphorus to cultivated soils – the supply of which often limits biological production and productivity. Phosphorus is a chemical element that is essential to life because of its role in numerous key molecules in the 'storage and processing of genetic information' (DNA and RNA), as well as a major component in the "energy currency" of cells as ATP and of the redox generating molecules like NADP. Phosphorus is also a major component of cell membranes as phospholipid layers containing hydrophilic phosphate groups. Given these crucial roles the pool of biologically available P controls ecosystem productivity to a considerable extent.

In natural environments, the biological availability of phosphorus is determined by the abundance of metal ions such as Ca2+, Fe3+ and Mg2+, which cause phosphorus to precipitate at pH values above 7.0. The P-content in average soil is about 0.05% (w/w) but only 0.1% of the total P is available to plants (Scheffer and Schachtschabel, 1992). As only, orthophosphate ions (H2PO4- and HPO42- depending on the pH) can be assimilated in appreciable amounts (Beever and Burns, 1980), the free inorganic P ion in soil plays a central role in P-cycling and plant nutrition. Global distribution of soil "phosphorus retention potential" is based on an integrated model of variables (e.g. soil temperature and vegetation cover) that influence phosphorus solubility and precipitation and consequently its availability. However, large amount of P that is added to the soil as fertilizer to overcome this malady eventually ends up in rivers, lakes and oceans where it causes deterioration of water quality by accelerated P transfer in surface run-off explained by the term eutrophication. These issues highlight the non-sustainable nature of current P usage pattern. Indeed, it has been estimated that human activites have amplified rates of P cycling globally by ~400% relative to pre-industrial time, far more than for carbon (~13%) or even nitrogen (~100%). To achieve P sustainability, farms need to become more efficient in the manner of using P while society as a whole must develop technologies and practices to recycle P.

Plants are comparatively less efficient in extracting otherwise unavailable phosphorus from the soil environment. However, during the last one decade, major quantitative trait locus (QTL) associated with P-deficiency tolerance 'phosphorus uptake 1 (Pup1)' has been identified in rice and tolerant Pup1 breeding lines of rice have proven effective in field trials. Previous efforts to link Pup1 with known P-uptake related mechanisms showed that Pup1 near-isogenic lines (NILs) had improved root growth under stress, but the underlying mechanisms remained enigmatic, indicating that Pup1 might act through a new mechanism or that the underlying gene may be missing in the reference genome. This has now been linked to a protein kinase named phosphorus-starvation tolerance 1 (PSTOL1) (Gamuyao et al., 2012). Phenotypic analyses conducted in two different locations and P-deficient soil types (from fields that had not received P fertilizer for up to 40 years) showed that high expression of the PSTOL1 transgene rice enhanced grain yield by more than 60% under P-deficient conditions in both varieties.

Microbial activities affect the phosphorus retention potential through enzymatic reaction and the capacity to affect the pH of their growth environment – the domain of phosphate-solubilizers. This include several mechanisms like enzymatic release of phosphorus by phosphatase and phytase activities mineralizing organic phosphate, chemolithotrophic microorganisms including Thiobacillus and Nitrosomonas mobilizing inorganic phosphate through the production of sulphuric acid and nitrous acid, respectively and wide genera of heterotrophic microorganisms mobilizing inorganic phosphate through the production of organic acids. Most transfers within the phosphorus cycle do not alter the oxidation state of phosphate enabling increment of biologically available phosphorus in an otherwise P-limited environment.

Among the best-studied microbial processes in the phosphorus cycle is the function of acid and alkaline phosphatases, two enzymes that are distinguished only by the optimum pH of activity with acid phosphatase predominating among the fungi. Alkaline phosphatase is widely distributed among the prokaryote, where it functions as a non-specific phosphomonoesterase through the formation of a covalent phosphoseryl intermediate. In addition to phosphatase activity, many prokaryotes are known to express polyphosphate kinase which catalyzes the production of phosphate polymers. Polyphosphate kinase activity is the key enzyme that reduces the phosphorus load of wastewater effluents to levels that do not lead to the eutrophication of receiving aquatic ecosystems.

Most studies concerned with microbial enzymes involved in phosphorus cycling aim at biotechnological applications in local environments. There are several advantages of developing genetically-modifieded plant growth promoting bacteria over transgenic plants for improving plant performance: (1) With current technologies, it is far easier to modify a bacterium than complex higher organisms, (2) Several plant growth-promoting traits can be combined in a single organism, and (3) Instead of engineering crop by crop, a single, engineered inoculants can be used for several crops, especially when using a non-specific genus with wider bio-geographical distribution. Introduction or over-expression of genes involved in soil phosphate solubilization (both organic and inorganic) in natural rhizosphere bacteria is a very attractive approach for improving the capacity of microorganisms to work as inoculants.

While innovations for improved agricultural efficiency and for new P recycling pathways, including those involving new forms of biotechnology, can contribute much to the achievement of P sustainability, it is unlikely that technological innovation alone can be the answer. Instead, system-level changes with wider coverage are necessary. These changes may need to involve diet preference (less meat to reduce the total P footprint of food production), societal attitude (recycling of human waste), civil infrastructure (urban design to facilitate P recycling in the food chain), regulatory frameworks (encourage evaluation of and potential adoption of genetically modified crops, animals and microbes) and institutions (development of governance protocols for P that cross food production and sanitation domains). In the overall P chain from agriculture field application to food on the table the main constraint is poor use efficiency at field level. The added societal dimensions imply that achieving P sustainability will be a long-drawn battle as it will probably need a 'radical redesigning of agriculture' (Fedoroff et al., 2011).

Objectives of the Workshop

1. To ascertain the pools and fluxes of P with a view to understand the underlying biogeochemical P cycle and its perturbation.
2. Locate the P-footprint and identify the various steps, from the Farmers' field to fork which need improvement in their efficiency.
3. To ascertain the level to which the poor P use efficiency is affecting the environment in terms build up of in the lakes, water bodies, river systems, coastal and oceanic systems.
4. To recover/reutilize the P in the food chain including human excreta, urine and shallow seas.
5. To encourage steps to enhance solubility of P in agricultural soils and biotechnological approaches with improved root systems.
6. Evolve strategies for various extents of P threatened future scenarios in agriculture section as well as geo-political threat potential to India.
7. To discuss/explore the possibility of the Establishment of Centre for nutrient sustainability which pursues research on fundamental biogeochemical processes in agriculture and on policy options working with practitioners and policy makers.

Workshop Proceedings

Inaugural Session

The inaugural session was chaired by Prof. R.B. Singh, President, National Academy of Agricultural Sciences (NAAS), New Delhi with Dr. Adrian Johnson, Director, International Plant Nutrition Institute (IPNI), Africa Program. At the outset Dr. N. Raghuram, Vice-President, ING-SCON in his opening remarks welcomed all the delegates and briefly mentioned about the workshop. Prof. Y.P. Abrol, President ING-SCON, in his address explained the scope and outline of the workshop. He outlined the problem of P availability to Indian agriculture as India has to import almost all its requirement of P as rock phosphate. Dr. N. Khare from the Ministry of Earth Sciences, Government of India mentioned the ministry's viewpoint with reference to release of P to the oceans and the resultant eutrophication. He mentioned that the ministry has a very long term program to monitor the release of P and other nutrients on a decadal scale. Dr. Johnston of IPNI briefed the audience about the role of P in global food security and the dynamicity of the nutrient in sustaining the agricultural productivity. He mentioned that while natural P resources are getting limited, there is immense scope of recycling P from sewage, developing agro-practices like conservation tillage that would otherwise reduce the loss of P from soil and optimize use of P and other nutrients on an economical basis.

Prof. R.B. Singh, in his Chairman's address welcomed the idea of hosting such brainstorming workshop of topical importance. He thanked the organizers and especially Prof. Abrol on highlighting the issue of phosphorus in a policy environment where both producers and consumers (farmers) are more concerned about the nitrogen and nitrogenous fertilizers' assured availability which is considered as the first step for ensured crop productivity under intensive agriculture. He emphasized that there is global scarcity of rock phosphate and India needs to import almost entire amount of its requirement. Prof. Singh mentioned of the nine interconnected planetary boundaries affecting human existence on the earth. He pointed out that phosphorus is more important than nitrogen because of price, handling and misuse. He mentioned of three Ps, namely permanency (sustainable use), productivity (in terms of maximizing P-use efficiency of the growing crop) and profitability to the farmers. He stressed on three Rs, namely recover, reuse and recycle the phosphorus.

The session ended with a vote of thanks offered by Prof. T.K. Adhya, Coordinator, ING-SCON and thanked Prof. R.B. Singh for his treatise on the subject and support extended to ING-SCON from the academy. He also thanked Dr. Johnston for his focused treatment of the subject and Dr. N. Khare for active help and financial support from the ministry for conducting this brainstorming workshop.

The inaugural session was followed by different technical sessions.

Keynote addresses: Chair – Dr. Adrian Johnston

Session on keynote addresses was organized to brief the background details of P scenario in a global vis-à-vis Indian context. The first lecture was given by Dr. Amit Rastogi, Vice-President – Technology, Coromandel International Limited, Chennai. He mentioned that the key challenge is to produce P-fertilizers in India at a lower cost by integrating backward into manufacture of purified phosphoric acid. It was pointed out that organo-mineral fertilizers such as NPK + Humic Acid can improve the P utilisation efficiency and organic fertilizers improve the soil OC and structure and help to supplement N and P from mineral fertilizers.

The second lecture delivered by Prof. S.K. Sanyal, former Vice-Chancellor, BCKVV West Bengal, highlighted phosphorous chemistry in relation to its availability for crop uptake. He emphasized for a relook for soil testing methods for evaluation of plant available Phosphorus. He also stressed for research on soil pH and P Availability and competitive anion interactions with P in acid soils. He also mentioned that P strongly competes with Molybdenum (Mo) for the active sites, thereby increasing Mo availability in acidic soils through competitive ligand exchange mechanism.

The next lecture given by Dr TK Adhya, ING-SCON outlined issues in relation to bioengineering for efficient P management in agriculture. He mentioned that a thorough integration of plant breeding, genetic engineering, P fertilization and cultivation management issues can result in a better understanding of P management in agriculture. The next lecture given by Dr HN Chanakya of Indian Institute of Science focused on the recovery of P from waste streams and its reuse by putting it back into crop system.

Technical Session I: Increasing P-use Efficiency and its Economics (Chair: Dr. B.S. Dwivedi)

The technical session focused on increasing P-use efficiency in agriculture. **Dr. R.K. Tewatia**, Chief (Agricultural Sciences), The Fertilizer Association of India, New Delhi in his presentation, mentioned that India's import dependence for P is >90% and efforts to be made is to increase availability and utilize indigenous rock phosphate. **Dr. Sudarshan K. Dutta, IPNI** outlined increasing P-use efficiency in Crops. He mentioned that the added P is not irreversibly fixed in forms that are unavailable to plants, rather plant root can take up P accumulated as residue in the soil. Accordingly, P-use efficiency must be measured over an adequate period of time and PUE needs are to be determined by Balance Method over Difference Method as the difference method does not consider the residual effect of added P. **Dr. V.K. Singh** of the Institute for Farming Systems Research. Modipuram highlighted P management under rice-wheat cropping system for enhancing P use efficiency and soil health. He suggested efficient fertilizer P management, integrated plant nutrient supply systems, site-specific nutrient management and integration of RCTs along with organic/residue recycling as key to enhancing P use efficiency in rice-wheat system. **Dr. Kaushik Majumdar**, **IPNI** South Asia Program, outlined P-Fertilizer use economics in cereals and concluded that P response of cereals is highly variable and is influenced by soil characteristics and growing environment of the crop. P application, therefore, must be based on economic assessment of application rates, nutrient response, cost of phosphate and minimum support price of the cereals. **Dr. K. Sammi Reddy** of CRIDA, Hyderabad mentioned about emerging strategies for enhancing external and internal P-use efficiency in different crops/cropping systems and emphasized on the adoption of already available P management strategies at farmers' level and focus on "Developing Product Strategies" for future. **Dr. T. Satyanarayana, IPNI** outlined regarding Optimizing Phosphorus use in Cereals through Innovative Decision Support Tools based on '4R Nutrient Stewardship Concept' that includes right source of nutrients at the right rate, right time, and in the right place. He briefed the audience on 'Nutrient Expert' – a decision support tool for making optimized P recommendations and improve productivity of cereals.

Technical Session II: P availability and using low grade P rocks (Chair: Dr. A. Subba Rao)

In this session, **Dr. A. N. Ganeshamurthy** of IIHR, Bangalore mentioned about finite phosphate reserves and P-needs of Indian soils. He mentioned commercialization of the available beneficiation technologies (washing, screening, de-sliming, magnetic separation, flotation and calcinations) to upgrade the P_2O_5 content to at least 25-30%, developing new and economically viable technologies for utilization of indigenous low grade phosphate as fertilizers either directly or by developing some suitable composition, encourage utilization of indigenous rock phosphates as direct source of P in acid soils, particularly in peninsular region, North-East region and coastal areas and exploit VAM technology and encourage research. **Dr A Subba Rao,** IISS, Bhopal mentioned about identifying and using new P sources, including low quality P forms with improved plant availability, reduced transport and spreading costs, and recycling of waste materials. He also pointed at improving crop and fertilizer management to increase P use efficiency including selection of plant species with root system tolerant to low–P status soil, better utilization of mycorrhizae and P solubilizing organisms, and improved fertilizer application techniques. **Dr. Sushanta Kumar Pattanayak**, OUAT, Bhubaneswar outlined strategies to rationalize P supply through direct use of phosphate rocks in acid soils where soil acidity is sufficient to dissolve the insoluble phosphate (pH<5.5), using mixture of PRs and SSP, where soil acidity is not enough to dissolve PRs (pH5.5-6.5), use of modified/compacted/pelleted products of phosphate rocks and use of biological agents namely GM, PSM and AM etc. for increased efficiency of Phosphorus.

Technical Session III: Role of Mycorrhizae (Chair: Dr. D. J. Bagyaraj)

This session which was organized to take stock of the role of mycorrhizae in the mobilization of bound-P had two presentations. **Dr A Subba Rao**, IISS, Bhopal talked about the possibilities for Improving the P-use efficiency using mycorrhizae for solubilization of P. **Dr D. J. Bagyaraj**, Bangalore outlined the process of microbially mediated mobilization of native and applied P. He mentioned increased yields in tomato ranging from 25-46% following inoculation with different AM fungi. The increased yields were obtained with use of only 50% recommended P. He concluded that AMF, PSM & other microbial inoculants play – important role and they are cost effective, environment friendly and improve soil health and boon to farmers, especially in developing countries.

Day 2 : Saturday, January 19, 2013

Technical Session IV: Microbes and P mobilization (Chair: Dr. T.K. Adhya)

Dr. G. Naresh Kumar, MS University, Vadodra highlighted the role of rhizospheric microbes for effective mobilization of bound P and supporting P-nutrition of crop plants. He suggested that biotechnological approaches could be exploited to develop novel P biofertilizers from native rhizobacterial population that are well adapted to the specific environmental conditions and also possess good PGPR traits. He mentioned that P-solubilization can be incorporated in N_2-fixing bacteria *viz Rhizobium, Herbaspirillum* and effectively used for improving plant nutrition for both P and K. **Dr. B. Hameeda**, Osmania University, Hyderabad, with extensive data from field experiments demonstrated strategies to harness the P-solubilization potential of soil microorganisms for improving P nutrition of crop plants. **Dr. K. Annapurna**, IARI, New Delhi explained use of plant growth promoting rhizobacteria and its use in enhancing P mobilization in cropping system.

Technical Session V: P and animal nutrition/production (Chair: Dr. K.K. Vass)

First presentation in the session was given by **Dr. S.K. Samanta**, CIFRI, Barrackpore who mentioned that in general, fish stock increases with increase in the level of primary production and these relationships are applicable only to water bodies in which the P load is manifested as planktons. Highly eutrophic water bodies have dominant populations of carps. He provided example of case study on the use of fish as bio-remediating agents to maintain water bodies in proper condition and not getting eutrified. **Dr. K. Sharma**, CARI, Izatnagar explained the use of low-P diet and use of phytase enzymes in the diet of livestock for controlling the level of P in the excreta. The later being often used as plant manure in cropped field leads to release of P in the environment. **Dr. N.K.S. Gowda**, National Institute of Animal Nutrition and Physiology, Bangalore reviewed the status of P nutrition in animal production and indicated general problems of lower utilization of phytin by monogastric animals (Pig, Poultry), higher fecal excretion of P leading to water pollution, requirement of desired dietary level in ruminants and monogastric animals and improvement of gut bioavailability being the major challenge. He recommended use of enzyme (phytase) in the diet of animals and recommended use of low-phytin containing varieties of maize as feed. **Dr. A.B. Mandal**, CARI, Izatnagar briefed the audience about the nutritional management of phosphorus pollution from poultry waste.

Technical Session VI: P and eutrophication (Chair: Dr. N. Khare)

The first presentation in this session was by **Dr. Gurmeet Singh** of JNU who presented an overview on phosphorous dynamics in the coastal marine environment of India. The **high productivity of mangrove forests**, its geomorphological position at stronger tidal regime with regular rainstorm, plus non litter retaining feature of mangrove tree have made the 'outwelling' hypothesis more conceivable than in salt marshes. Mangrove soils are expected to contain a high proportion of organic P compounds due to their generally high organic matter content. Although organic P is the major fraction, the inorganic phosphates probably represent the largest potential pool of plant-available, soluble reactive phosphorus. Together with algal growth, leaf litter fall and decomposition plays an important role in the phosphorus cycling of fringe mangrove sediments. In the next presentation, **Dr. A.K. Misra** of BHU, Varanasi presented information on ecological perturbations due to P-use in agriculture. With extensive mathematical modelling, he tried to explain the stability analysis of downstream developments in eutrophication as a result of P enrichment in water bodies. **Dr. P. Selvam** of Anna University, Chennai detailed the participants of the workshop on nutrient dynamics and budget for coastal ecosystem from southwest coast of India with a case study on Vembanad lagoon. To understand the flux of material and energy in coastal systems and to estimate the role of coastal areas as sources or sink of C, N and P, the International Geosphere Biosphere Program - Land-Ocean Interaction in the Coastal Zone (IGBP-LOICZ) program was used. He explained that in order to have a better flux estimation it is essential to study the role of suspended matter in the DIP flux calculation, incorporation of other forms of P (DOP, PIP), quantification on inputs like groundwater discharge and sewage discharge into the systems and human induced phosphorus inputs to a watershed through application of NAPI (Net Anthropogenic Phosphorus Inputs).

Technical Session VII: Future initiatives to increase P utilization (Chair: Prof. Y.P. Abrol)

In this session there were two presentations. In the first talk, **Dr. J.C. Tarafdar** of CAZRI, Jodhpur explained phosphorus mobilization: current status and future outlook in the backdrop of the recent developments in nanotechnology for P management. The benefits accrued due to (a) high surface area, (b) thorough dispersion in soil matrix, (c) no coordination with H_4SiO_4, (d) No fixation with $CaCO_3$, Fe, Al, (e) Little or no complex with soil organics, (f) High nutrient use efficiency. He also mentioned that some nano particles are co-factors of P mobilizing enzymes (phosphatases, phytase) and may therefore enhance native P mobilization. In the next presentation, Dr. Naveen Kalra of Tata Chemicals explained advanced crop nutrition solutions for sustainable agriculture with special emphasis on P for its effective management. He also cited experimental results on the use of nanoparticles as smart delivery system for plant nutrients.

Concluding Session

The concluding session was jointly chaired by Dr. T.K. Adhya of ING-SCON and Dr. Adrian Johnston of IPNI. It was mentioned that sustainable P management is of extreme importance to India as its own natural reserves are negligible and over 90% of P requirement is met by import. Recent estimates suggest that while global reserve might last for between 50-300 years more, their accessibility may become increasingly critical to our food security. It was, therefore, suggested that attempts should be made for consolidation of the available knowledge on source, sinks and flows of phosphorus and enlistment of the relevant institutions of expertise and bodies of governance to be networked to address the identified issues. Also, long-term observation on a system basis in a time-scale to ensure sustained sustainable management of P resources for life processes and include P relationship among the interconnected planetary boundaries initiated. Overall, identification of gaps in the current knowledge on the Indian region and quantification of the biogeochemical cycle of P in the region, covering the land-water-ocean interactions be ensured.

The meeting was ended with the vote of thanks given by Dr. M.K. Tiwari on behalf of ING.

Sustainability Challenges for Efficient Management of Phosphorus – the Indian Scenario

Recommendations for Research and Policy from the Workshop

on

"Phosphorus Cycle: Sustainable Management of Resources, Food Security and Environment"

Held at NAAS, New Delhi, during January 18-19, 2013

Phosphorus (P) is essential to life and serves multiple roles that sustain living systems, both in terms of its role in biology and its importance as an ecological and evolutionary factor. The element plays a central role in life's structures and metabolic pathways, its biogeochemical scarcity, impact on ecosystems and essentially its key role as fertilizer in crop and animal productivity, sustaining human enterprise. The P biogeochemical cycle involves mainly in terrestrial and aquatic ecosystems and interactions with the atmosphere is minimal. Globally, the source of P is from geological sedimentary rocks and the rock phosphate mining in 2011 amounted to 191 Mt (Scholz and Wellmer, 2012), corresponding to 25 Tg P yr^{-1}. Most of the P mined is added to agricultural soils as P-fertilizer (18 Tg P yr^{-1}; Heffer and Prud'Homme, 2012) and a small quantity used in the industry especially for the manufacture of detergents and in food industry. Overall, 82% P is required for fertilizers; 7% as a nutrient in feedstock; 11% as pharmaceuticals and Industry.

Once applied to agricultural soils, P moves through the agricultural and animal production systems and can accumulate in the agricultural soils at an estimated amount of 12 Tg P yr^{-1} (Bouwman et al.,2009). Giving an estimated full-chain nutrient use efficiency for phosphorus (NUE_P) of 12-20% (Bennett et al., 2001), around 3-5 Tg P yr^{-1} is excreted through human excreta and the quantity of P reaching the rivers by sewage systems amounts to 1-3 Tg P yr^{-1} (Van Drecht et al., 2009). Of the rest, the major losses occur in the steps from mining to preparation of mineral fertilizer and other P products and from mineral fertilizers to crop and livestock production. Once in surface continental water, part of P is trapped in sediments and about 9 Tg P yr^{-1} are delivered to coastal waters where it can contribute to eutrophication leading to localized hypoxic and anoxic conditions.

Deficiency of P in agricultural soils has long been recognized by the agronomists, emphasizing the need to replenish soil P in order to enhance and sustain productivity. In natural environments, the biological availability of phosphorus is determined by the abundance of metal ions such as Ca^{2+}, Fe^{3+} and Mg^{2+}, which cause phosphorus to precipitate at pH values above 7.0. The P-content in average soil is about 0.05% (w/w) but only 0.1% of the total P is available to plants (Scheffer and Schachtschabel, 1992). As only, orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-} depending on the pH) can be assimilated in appreciable amounts (Beever and Burns, 1980), the free inorganic P ion in soil plays a central role in P-cycling and plant nutrition. These issues highlight the non-sustainable nature of current P usage pattern. Indeed, it has been estimated that human activities have amplified rates of P cycling globally by ~400% relative to pre-industrial time (Falkowski et al., 2000), far more than for carbon (~13%) or even nitrogen (~100%). To achieve P sustainability, farms need to become more efficient in the manner of using P while society as a whole must develop technologies and practices to recycle P.

While innovations for improved agricultural efficiency and for new P recycling pathways, including those involving new forms of biotechnology, can contribute much to the achievement of P sustainability, it is unlikely that technological innovation alone can be the answer. Instead, system-level changes with wider coverage are necessary. These changes may need to involve diet preference (less meat to reduce the total P footprint of food production), societal attitude (recycling of human waste), civil infrastructure (urban design to facilitate P recycling in the food chain), regulatory frameworks (encourage evaluation of and potential adoption of genetically modified crops, animals and microbes) and institutions (development of governance protocols for P that cross food production and sanitation domains). In the overall P chain from agriculture field application to food on the table the main constraint is poor use efficiency at field level. The added societal dimensions imply that achieving P sustainability will be a long-drawn battle as it will probably need a 'radical redesigning of agriculture' (Fedoroff et al., 2011).

In the above global backdrop, Indian situation is highly constrained. Given the fact that most of the P is mined from sedimentary rocks, India has deposits of only 306 Tg of all types and grades of phosphorite, which account for 0.19 per cent of the World resources. Much of it is low-grade P having less than 25-30 per cent P_2O_5 and is not suitable for fertilizer manufacture. Accordingly, India is mostly dependent on imports to an extent of 90% for meeting its domestic requirement of P. India imports rock phosphate, phosphoric acid and also P fertilizers from Jordan, Morocco, Senegal, Israel and South Africa. Further, P deficiency in Indian soils is widespread and to sustain increasing agricultural productivity, consumption of P fertilizer in India increased from 0.053 Tg in 1960-61 to 7.3 Tg in 2009-2010. This is expected to rise to 14.0 Tg in 2030-2031. Since increasing demand is sending the global price of phosphate rock northwards, India has to spend a large amount of its valuable economic resources for such imports. Additionally large tracts of croplands in India suffer from physico-chemical and nutrient imbalances resulting low efficiency of applied fertilizer P. Solubilization of P is essential to enhance its availability. While use of microorganisms has shown promise, the impact had not been uniform on a large scale and also exhibit lack of ecological fitness.

Phosphorus mostly moves in a linear direction from mines to fertilizer production centres to agricultural fields for crop production, processing and consumption where a large fraction may become either agronomically inactive, unsuitable for recycling due to fixation, contamination or dilution, and as polluting agent of surface water. In order to encourage and ensure sustainability of P use, it is essential to have need-/ evidence-/ research-based policies towards an integrated understanding of the complete biogeochemical cycle of P with relevance to India. Various options that need to be exercised include:

1. Agronomic options including active recycling of P locked in organic residues and enhanced release of unavailable-P fractions

2. More efficient crops in exploiting the soil volume and in extracting P from 'unavailable' chemical pools in the soil.

3. Develop methodologies to use microbes/mycorrhiza to solubilize P in the rhizosphere and their exploitation.

4. Reliance on P fertilizer production from sources recycled within the human food chain'.

Being a finite natural resource and in anticipation of P supply dwindling in future, enhancing P use efficiency to the highest biological and agronomic limits, as well as recovering P ending up as a pollutant in our aquatic resources, both freshwater and marine, are the ways to make sustainable use of P. Accordingly, research/policy recommendations on phosphorus as an illustrative framework are listed below for the consideration of all stakeholders for their respective initiatives.

1. **Need for a country-wide assessment**:

Sustainable P management is of extreme importance to India as its own natural reserves are negligible and over 90% of P requirement is met by import. Recent estimates suggest that while global reserve might last for between 50-300 years more, their accessibility may become increasingly critical to our food security. In this background it is essential to address the following on a priority basis:

a. Consolidation of the available knowledge on source, sinks and flows of phosphorus and enlistment of the relevant institutions of expertise and bodies of governance to be networked to address the identified issues.

b. Long-term observation on a system basis in a time-scale to ensure sustained sustainable management of P resources for life processes and include P relationship among the interconnected planetary boundaries.

c. Identification of gaps in the current knowledge on the Indian region and quantification of the biogeochemical cycle of P in the region, covering the land-water-ocean interactions.

d. Establishment of an integrative data centre for nutrients including phosphorus, encompassing all the process domains, as a national resource for research and policy.

2. Ocean-land interaction:

a. Since P flow is mostly open-ended from soil to riverine flow and ultimately to the ocean, determination of intrasystem P fluxes and coastal upwelling leading to the release of P to the outer ocean need to be quantified by field and modelling studies.

b. Fine-tune the current understanding on the extent and prevention of eutrophication and other effects of P pollution in coastal areas including regular monitoring of algal blooms and other changes in the biodiversity due to P loading of coastal, estuarine and marine ecosystems.

c. Identification and quantization of hypoxic/anoxic coastal areas as affected by P loading and validate data on downstream effects including reported large scale fish kills in Mandapam and other coastal areas.

3. Agriculture:

Agriculture being the major consumer of P, source of which is determinate, greatest challenge is that all out efforts are made to increase the efficiency and ensure minimum leakage from the system. This will ensure reducing the need for external fertilizer while allowing farmers to increase and maintain yields and thus improve their standards of living.

a. Development of and wider adaptation of P nutrient use efficiency (NUE_p) vis-à-vis overall crop management, realistic application of the technology and its economic evaluation.

b. Use interactive decision support system tools for increasing P use efficiency in increasing crop productivity.

c. Periodic soil testing based soil health determination, regulating use of phosphorus in agriculture.

d. Need for making technologies of increasing P-use efficiency more affordable and increase awareness among the farmers through re-education for adoption in the context of integrated agriculture.

e. Wider adoption of organic manures and biofertilizers (P-solubilizers, PGPR and AM fungi) to reduce dependence on inorganic P fertilizers; ensuring policy support through effective quality control of the biofertilizer and mechanism to increase their use by economic measures including provision of subsidy.

f. Exploitation of novel cropping system like cereal-legume and legume-based pasture systems on a wider scale to increase extraction of soil-immobilized P.

g. Since loss of P through soil erosion is a major event, use of conservation agriculture like no-tillage cropping and specific management practices to reduce erosion would be highly useful.

h. Use genetic engineering strategies to improve P-use efficiency of crop cultivars including exploitation of 'P-uptake' (*pup*) genes, proton translocating pyrrophopatases (*PPase*) and other P-starvation response plant (PSTOL) genetic systems. Although some advances have already been achieved in case of field crops like rice and maize, this need to be widely exploited.

4. Fisheries and aquaculture:

Indian fisheries sector has made great strides and current production (2010-2011) is estimated at 8.1 million tons with 61% contribution from inland sector. The bulk of inland fisheries are contributed by intensive aquaculture by application of management practices involving inputs viz., organic manuring, inorganic fertilization including P apart from supplementary feeding of fish stocks and high density of seed stocking.

a. While aquaculture production processes are understood sufficiently clearly, attempt should be made to understand the nutrient cycle especially inflow and outflow mechanism of P in different land-based production units including their impacts on open-waters (river systems and associated water bodies).

Use successful models of aquaculture in downstream water reserves and tropical sewage-fed fisheries to recycle and recover nutrients including P.

5. Poultry and animal sciences:

With improvement in life style, there is increased emphasis on inclusion of poultry and animal components in the human diet. Only 4-15% of the P consumed by the livestock becomes available for human consumption and there is substantial scope for improving the efficiency of P supply. Some of the intervention points could be:

a. Reducing dietary P inputs through judicial use of feedstuff and improving utilization of P by augmenting availability through innovative measures.

b. Desired dietary level of P in ruminants and monogastric animals and improve gut bio-availability through better bioavailable inorganic sources and balancing of different minerals (Ca, P, Mg).

c. The N: P ratio of most poultry litter is close to 2.5 :1 against the requirement of N to P ratio of 8:1 for most of the crops. This results in P build-up in soil and contributing to eutrophication in downstream areas and can be avoided through intelligent recycling.

d. Improved manure management from animal husbandry to effectively recycle nutrients including P as crop resource.

6. Close the biogeochemical cycle through effective recovery and recycling:

a. Ensure policy measures to recover and recycle phosphorus-containing wastes to enhance food security while also reducing the polluting effects of phosphorus run-off.

b. With a population of ~1.3 billion, India is estimated to release between 0.38-1.02 Tg P per annum. An effective mechanism to recycle the human wastes for agriculture through innovative steps like urine-separating toilets would ensure capture nutrients for return to the soil as well as improved sanitation in the developing world.

c. Rural wastewater and sewage sludge which is mostly dumped on the soil should be intelligently used for recovery by crop.

d. Effective pre-treatment of urban solid wastes, volume of which is increasing by day due to increased urbanization, would ensure effective recovery of P and other nutrients from such sources and return to crop fields for increasing production.

7. Chemicals and fertilizers:

a. Development of new processes and new P-fertilizer products for maximizing P-utilization efficiency, especially using low-grade P-rocks available indigenously.

b. Organic compounds in soils increase P availability by (1) formation of organophosphate complexes that are more easily assimilated by plants (2) anion replacement of $H_2PO_4^-$on adsorption sites (3) coating of Fe/Al oxides by humus to form a protective cover and reduce P adsorption. Thus development of organo-mineral fertilizers such as NPK + humic acid can improve the P utilization efficiency.

8. Ecology and environment:

a. Survey of water bodies polluted with nutrients to demarcate hotspots and establish leakage of phosphorus to the environment and its downstream effects including biodiversity losses and eutrophication.

b. With substantial net accumulation of P in agricultural soils, there is substantial scope for improving the efficiency of P supply in the global system. Effective.

9. Role of ING-SCON on the issue:

In order to realize the objectives underlying the above recommendations, there is a need to continue to forge voluntary alliances among scientists, policy-makers and other stakeholders unhindered by disciplinary or organizational boundaries. This could be further institutionalized by creating an Integrated Nutrient Centre. The catalytic role played by ING-SCON in this direction is notable. ING should continue to bring together diverse scientific communities, policy makers, industry and other stakeholders from India and abroad on a common platform to build synergies for research and policy, as well as undertake coordination and dissemination roles.

More specifically, ING-SCON should speedily pursue its proposed programs on:

a. Regional assessment of the state of phosphorus in different regions of India linked to various sectors of activities based on consolidation of the existing literature.
b. Program to assess technologies for increasing P-use efficiency in agriculture across geographical boundaries and ecologies to capture all the phosphorus flow interfaces starting from the agricultural fields through river basins up to the coastal areas and ultimately transfer to open seas.
c. Assessing phosphorus footprint of day-to-day activities of urban and rural population including food-chain at large.
d. Sensitize, using its South Asian Centre and active support of GPNM, the scientific communities of the SAARC and other south Asian countries to initiate consultations on P issues holistically.

Annexure I
Technical Programme

PHOSPHORUS CYCLE: SUSTAINABLE MANAGEMENT OF RESOURCES, FOOD SECURITY AND ENVIRONMENT

Brain Storming Workshop
January 18-19, 2013

Organized by ING-SCON

Sponsored by MoES, Govt. of India
Venue: ICAR, TRAINING HALL, NASC Complex, New Delhi – 110012

PROGRAMME

Friday, January 18, 2013

09.00 Registration
10.00– 11.00 – Inaugural Session
Session Chair: R.B. Singh, President, NAAS

Opening Remarks : N Raghuram
Scope and outline of the workshop : Y P Abrol
Remarks: N Khare (MoES)
Inaugural Remarks : Adrian Johnston
Remarks by the session Chair : R B Singh
Vote of thanks : T K Adhya

11.00 – 11.30 – Tea Break
11.30 – 01.00– Keynote Addresses
Chair: A. Johnston

Keynote address – 1: Phosphorous Cycle: Sustainable Management through New Developments in Phosphatic Fertilisers - **Amit Rastogi**

Keynote address – 2: Phosphorus Chemistry in Relation to Its Availability to Plants - **Saroj K. Sanyal**

Keynote address – 3: Bioengineering for efficient P management – **T K Adhya**

Keynote address – 4: Recovery and reuse of phosphorus from sewage and urban solid wastes – a key to a sustainable future – **H N Chanakya**

01.00–02.00– Lunch

02.00 – 03.30 Technical Session – I : Increasing P-use efficiency and Economics

Chair : B.S. Dwivedi

1. Crop production in acid soils of eastern India--need to re-emphasize on lime and P application –**A.K. Sarkar**
2. Phosphorus use efficiency in crops: An issue to be addressed by multiple year study – **Sudarshan K. Datta**
3. Phosphorus Management under Rice-Wheat Cropping System for enhancing NUE and Soil Health – **V. K. Singh**
4. P Fertilizer Use Economics in Cereals: Experience from the IGP – **Kaushik Majumdar**
5. Emerging strategies for enhancing external and internal P use efficiency in different crops/cropping systems –**K. Sami Reddy**
6. Optimizing P use in Cereals through Innovative Decision Support Tools **- T. Satyanarayana**

03.30 –04.00 Tea Break

04.00 – 05.00 Technical Session – II : P availability and using low grade P rocks

Chair : A. Subbarao

1. Finite phosphate reserves and phosphorus needs of Indian soils – **A N Ganeshamurthy**
2. Rock phosphate deposits in the world and India – **A Subbarao**
3. Strategies to Rationalize P Use through Rock Phosphate in Acid Soils: Orissa Experience – **S. K. Pattanayak**
4. Phosphorus fertilizer use in India: Industry perspective – **R K Tewatia**

05.00- 05.45 Technical Session – III : Role of mycorrhizae

Chair: D J Bagyaraj

1. Role of mycorrizae in solubiliztion of P- **Alok Adholeya**
2. Possibilities for improving the phosphorus use efficiency using mycorrhizae, microbes and root modification – **M C Manna**
3. P nutrition of crops through arbuscular mycorrhizal fungi – **D J Bagyaraj**

Saturday, January 19, 2013

10.00-11.15 Technical Session – IV : Microbes and P mobilization

Chair : T K Adhya

1. Phosphorus Nutrition – Challenges and Microbial mobilization –**G Naresh Kumar**
2. Phosphate solubilizing microorganisms: harnessing their potential for improving P nutrition to plants –**B Hameeda**
3. Strategies for harnessing P solubilization potential of multifunctional plant growth promoting rhizobacteria for maximizing P nutrition of crops and their overall health –**K. Kumar**
4. Soybean-bradyrhizobial interactions – developing strategies for increased yields- **K. Annapurna**
5. Influence of inorganic, biological and organic sources on soil fertility, yield and nutrient uptake of paddy in ultisols of Mizoram –**K. Laxminarayana**

11.15 -11.45 Tea Break

11.45-12.45 Technical Session – V : P and animal Nutrition/production

Chair : K K Vass

1. Phosphorus transformations, eutrophication and fish production – **Srikanta Samanta**
2. Phosphorus Utilization in Livestock Production System - **K Sharma**
3. Phosphorus in farm animal feeding – Issues and environmental concerns – **N K S Gowda**
4. Nutritional management of phosphorus pollution from poultry waste – **A B Mandal**

12.45–01.45 – Lunch

01.45 – 02.45 Technical Session – VI : P and eutrophication

Chair : N Khare

1. Phosphorous dynamics in the Coastal marine environment of India – **A L Ramanathan/ Gurmeet Singh**
2. Role of biologically active nutrient (phosphorus) in maintaining stability of aquatic ecosystems – **Ashwani Wanganeo**
3. Ecological perturbations due to phosphorus use in agriculture- **A K Misra**
4. Nutrient (N and P) dynamics and budget for muddy coastal ecosystems (mangroves and coastal lagoons) of India- **R. Ramesh/ Paneer Selvam**

02.45–03.00 Tea Break

03.00 – 03.45 Technical Session – VII : Future initiatives to increase P utilization

Chair : Y P Abrol

1. Phosphorus mobilization: current status and future outlook – **J.C. Tarafdar**
2. Advanced crop nutrition solutions for sustained agriculture- **Naveen Kalra**
3. Physiological and molecular strategies of plants for improving phosphorus efficiency- **Renu Pandey**

03.45 – 05.00 Concluding Session

Co-Chair: A Johnston; Co-Chair: T K Adhya

General Discussion; Concluding remarks

Annexure II

PHOSPHORUS CYCLE: SUSTAINABLE MANAGEMENT OF RESOURCES, FOOD SECURITY AND ENVIRONMENT			
Organised by SCON-ING/IPNI on 18-19 January,2013 at NASC Complex, New Delhi			
S. No.	**Participant Name**	**Address**	**Email ID**
1	**Dr. N Khare**	MoES, New Delhi	neloy.khare@nic.in
2	**Prof. R B Singh**	NAAS, New Delhi	rb.singh@nic.in
3	**Prof. A. L. Ramanathan/ Dr. Gurmeet Singh**	Jawaharlal Nehru University (JNU), New Delhi	alr0400@mail.jnu.ac.in / gurmeet21@gmail.com singh.gurmeet@ymail.com
4	**Dr. J.C. Tarafdar**	Central Arid Zone Research Institute (CAZRI), Jodhpur	tarafdar@cazri.res.in,
5	**Dr. A.N. Ganeshamurthy**	Indian Institute of Horticultural Research, IIHR, Bangalore	angmurthy@gmail.com
6	**Dr. B S Dwivedi**	IARI, Pusa, New Delhi	head_ssac@iari.res.in
7	**Dr. D R Biswas**	IARI, Pusa, New Delhi	drb_ssac@iari.res.in
8	**Dr. K. Annapurna**	IARI, Pusa, New Delhi	annapurna93@yahoo.co.in
9	**Dr. P K Chhonkar**	IARI, Pusa, New Delhi	pkchhonkar@yahoo.com
10	**Dr. A K Patra**	IARI, Pusa, New Delhi	patraak@gmail.com
11	**Dr. A Subbarao**	Indian Institute of Soil Science, Bhopal	asrao@iiss.ernet.in
12	**Dr. Aswini Wanganeo**	Barkatullah University, Bhopal	profwanganeo@gmail.com
13	**Dr. K.K.Vass**	Ex-Director, CIFRI	vass.kuldeep76@gmail.com
14	**Dr. H. Chanakya**	IISc, Bangalore	hoysull@gmail.com
15	**Dr. K Sammi Reddy**	CRIDA, Hyderabad	ksammireddy@crida.in, ksreddy_iiss39@yahoo.com
16	**Prof. G. Naresh Kumar**	M.S. University, Baroda	gnaresh_k@yahoo.co.in
17	**Prof. D.J. Bagyaraj**	UAS, Bangalore	djbagyaraj@gmail.com
18	**Dr. Kusumakar Sharma**	IASRI, New Delhi	Ksharma52@gmail.com

19	**Dr. B Hameeda**	Osmania University, Hyderabad	drhami2009@gmail.com
20	**Dr. Krishan Chandra**	Additional Commissioner(INM), New Delhi	Krishan.rcof@gmail.com
21	**Dr. Adrian Johnston**	IPNI, Vice President	ajohnston@ipni.net
22	**Dr. V K Singh**	Project Directorate for Farming Systems Research, Modipuram, Meerut-250110	vkumarsingh_01@yahoo.com
23	**Dr. Kaushik Majumdar**	IPNI, Program Director	kmajumdar@ipni.net
24	**Dr. Sudarshan Dutta**	IPNI, Deputy Director	sdutta@ipni.net
25	**Dr. S. K. Sanyal**	Ex-Vice Chancellor, BCKV	sarojsanyal@yahoo.co.in
26	**Dr. A. K. Sarkar**	Retired Dean of Agriculture, Birsa Agricultural University, Ranchi	aksarkarranchi@gmail.com
27	**Dr. R. K. Tewatia**	Chief (Agricultural Services), FAI, New Delhi	ags@faidelhi.org
28	**Dr. Amit Rastogi**	Coromandel Fertilizers, Visakhapatnam	rastogia@coromandel.murugappa.com
29	**Dr. Paneer Selvam**	National Centre for Sustainable Coastal Management, Chennai	
30	**Ms Renu Sethi**	Vishakhapatnam	sethirenu95@gmail.com
31	**Dr. A B Mandal**	CVRI, Izatnagar	abmcari@rediffmail.com
32	**Dr. A K Misra**	Faculty of Sciences, BHU,Varanasi-221005	Akmisra_knp@yahoo.com
33	**Prof. Bijay Singh**	Punjab Agricultural University (PAU) Ludhiana	Bijaysingh20@gmail.com
34	**Dr. S. Samanta**	CIFRI, Barrackpore, Kolkata 700120	Samantacifri@yahoo.co.in
35	**Dr. K Laxminarayana**	ICAR, Mizoram, Kolasib	klnarayana69@rediffmail.com
36	**Dr. S K Pattanayak**	Professor, OUAT	Sushanta_1959@yahoo.com
37	**Dr. Naveen Kalra**	Tata chemicals	nkalra@tatachemicals.com
38	**Dr. T. Nagendra Rao**	Nagarjuna Group	tnagendrarao@nagarjunagroup.com
39	**Prof. R Ramesh**	Institute for Ocean Management, Chennai	rramesh_au@yahoo.com
40	**Dr. Inderpal Abrol**	CASA, Ne w Delhi	abrolip@gmail.com

41	**Dr. NKS Gowda**	National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore 560030	nksgowda@rediffmail.com
42	**Prof. Y P Abrol**	SCON, New Delhi	ypabrol@gmail.com
43	**Dr. T.K. Adhya**	SCON, New Delhi	adhyas@yahoo.com
44	**Dr. N. Raghuram**	SCON, New Delhi	raghuram98@hotmail.com
45	**Dr. M. K. Tiwari**	SCON, New Delhi	mk.tiwari2005@gmail.com
46	**Dr. Altaf Ahmad**	SCON, New Delhi	ahmadaltaf@rediffmail.com, aahmed@jamiahamdard.ac.in
47	**Dr. Himanshu Pathak**	SCON, New Delhi	hpathak.iari@gmail.com
48	**Dr. Renu Pandey**	SCON, New Delhi	renu_iari@rediffmail.com
49	**Dr. T. Satyanarayana**	IPNI, Deputy Director	tsatya@ipni.net
50	**Dr. S. C. Datta**	IARI, New Delhi	scdutta@iari.res.in
51	**Mr. Brijesh Kumar**	SSAC, IARI	
52	**Mr. Shashivind Misra**	IARI, New Delhi	
53	**Dr. M. Hassan**	IARI, New Delhi	
54	**Ms. Prachi**	CASA, New Delhi	
55	**Mr. Amit Kumar**	IARI, New Delhi	

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Professor YP Abrol
(ING-SCON)
F4, NASC Complex, CGIAR Block
Email: ypabrol@gmail.com, scon.prakriti@gmail.com