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Efficient Utilization of Phosphorus

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Preface

Phosphorus is as crucial as water and is second to nitrogen as the important limiting element for plant growth. Phosphorus is highly immobile nutrient with 1-3% of the total phosphorus and 15-25% of the applied fertilizer P is available to plants. It leads to a continuous build up of P in soil through fertilizer application. The problem is again aggravated since the rock phosphate (RP), the basic raw material used to manufacture P fertilizers, is non-renewable resource that is continuously getting depleted. Further, world's 67% of the RP is mined in just three countries: USA, China and Morocco.

Continuous application of P at higher rates to different crops may cause P pollution and also escalating prices of P fertilizer in the recent past may reduce the profitability of the farmers. Enhancing use efficiency of applied P in different crops/ cropping systems would be an economically viable and environmentally benign way of efficient P management. Suitable technologies are available for producing phosphate rich compost using low- grade RP. Another initiative may be use of Arbuscular mycorrhizae (AM) in both field and horticultural crops that will increase fertilizer use efficiency of P by increasing mobility in soil and reducing fixation. Using biotechnological approaches to transfer genes to create plant types that may mobilize more soil P from acid/alkaline soils could be the other route. Use of nano-P fertilizers and controlled release P fertilizers in enhancing P use efficiency may be explored. Development and implementation of sustainable technologies and strategies for the recovery of P from the organic wastes and sewage water for reuse in agriculture should be a priority.

Sustainable phosphorus use will require an integrated approach that combines efficiency and reuse, in order to reduce current phosphorus losses, minimize environmental impacts, conserve a finite resource and ensure all the farmers have access to phosphorus. Effective and inclusive governance and associated institutional arrangements to ensure long-term P security of the country through a combination of regulatory and economic instruments and a mission mode approach to utilize indigenous mineral and organic resources is needed to reduce dependence on import of P.

With the above backdrop, the National Academy of Agricultural Sciences (NAAS), organized a Brainstorming Session entitled 'Efficient Utilization of Phosphorus' on November 8, 2013 to consolidate the knowledge and on-going research activities as well as to suggest policy framework for the most efficient use of phosphorus. I am confident that this Policy Paper emanating from the Session would table a plan for priority research, strategic plan and policy action and will be used to influence policy, setting research directions and informing decision-makers.

The Academy appreciates the efforts of Dr. A. Subba Rao and his team in convening the brainstorming event. Grateful thanks are due to Resource Persons, Reviewers and Editors of the policy paper.

S Ayyappan
President

Efficient Utilization of Phosphorus

1. PREAMBLE

Phosphorus (P) is one of the essential nutrients necessary for the growth of all forms of life. The native soil P reserves are limited and are exhaustible under intensive agriculture. Phosphorus application that matches nutrient requirement of a crop based on yield target and indigenous soil nutrient supply is expected to provide larger profits as compared to blanket application of P fertilizers. This has become even more important in view of the recent increase of P fertilizer prices in the International market. The economic as well as the environmental implications of P escaping from farm lands is driving increased interest in bringing improved P use efficiency in focus. For nutrients that are retained in the soil, as P and K, the benefits that accrue are long-term in nature; therefore, their costs are usually amortized over several years. Applications at rates to build soil fertility are usually above the economic optimum nutrient rate for a one-year crop response, but may become economical over a longer time period when the responses in the following years are considered. On the other hand, transfer of soil P of cultivated land through erosion or runoff is a major cause of P-induced eutrophication in surface waters. This underlines the significance of P management in a given cropping system or growing environment (Majumdar et al., 2013).

World Rock Phosphate (RP) availability, the only economic source of P is estimated to peak by 2030 (Cordell et al., 2009) and thereafter a steep decline is envisaged. The estimates of RP reserves are subject to change with the updated information and discovery and with changes in economics and technology. Irrespective of the projections, world RP reserves will exhaust sooner or later, therefore addressing future P supply should be one of the most urgent priorities for the future sustainability of agriculture and humanity. About 95% of the phosphate rock mineral is used to produce fertilizer, animal feeds and pesticides. Rock phosphate reserve across the globe is estimated at 71,000 million tonnes (as P_2O_5) (United States Geological Survey 2012). The total resources of rock phosphate in India as per United Nations Framework Classification (UNFC) are placed at 305.3 million tonnes. The production of the rock phosphate in 2007-08 was 1.86 million tonnes. Rajasthan continued to be the principal producing state, contributing 94% of the total production followed by Madhya Pradesh with 6%. Grade-wise about 43% of the total production of rock phosphate was about 30-35% P_2O_5, 4% of 25-30% P_2O_5 and 53% of 15-20% P_2O_5 (Geological Survey of India, 2011).

Closer look into the fertility of Indian soils reveals that Indian soils do not have the ability to meet the demands for phosphorus of today's high-yielding crops. Soils of more than 80% of the districts represented low to medium P fertility categories indicating the necessity of P fertilization to produce optimum crop yields (Muralidharudu *et al*. 2011). Also, wide inter-regional variations exist in P fertility of soils, which are often masked in summarized country-level reports.

Chemical fertilizers have played an important role in making the country self-reliant in food grain production. Per hectare consumption of fertilizer nutrients improved from 92.2 kg at the end of the IX Plan (1997-2002) to 145 kg during 2010-11. The availability of fertilizers on a sustained basis is essential for food security and overall growth of the economy. To insure fertilizers at affordable prices to the farmers, the subsidy on them is an integral part of government policy. Phosphorus (P), besides nitrogen (N) and potassium (K), is one of the most important fertilizer nutrient elements, which decide the level of production and its sustenance. They will continue to be important since a huge amount of foreign currency is spent every year on their import. This is also accompanied by ever increasing subsidy on fertilizers. In either case it is imperative to restrict their application in right amounts only at the places where they are required.

Large quantities of finished products of fertilizer are imported from India every year, besides raw materials and intermediates for producing different fertilizers indigenously. In 2000-01, import of finished products (on N + P_2O_5 + K_2O nutrient basis) was 2.194 million tons (Mt), which rose to 12.208 Mt in 2010-11. Besides, currently about 5 million tonnes of rock phosphate, 2 million tons of phosphoric acid and 1.2 million tons of sulphur are imported every year. The availability of rock phosphate from domestic sources is about 1.86 million tons. Domestic availability of sulphur is about a million tons. In view of this, it is important to explore and exploit the possibility of using indigenous resources notably rock phosphates, organic and industrial byproduct P sources. Newer technology products such as nano-fertilizers have to be assessed for their suitability under the current agricultural scenario.

In light of the above, it is important to consolidate the knowledge and on-going research activities of the indigenous sources of phosphorus, and to make strategies for their efficient use. Most of the Indian rock phosphates are of low grade and the available technologies are not suitable to use them in the manufacture of high analysis fertilizers as DAP (46% P_2O_5) or SSP containing at least 14% or 16% P_2O_5, as required by the Indian fertilizer control order (FCO). Based on the knowledge generated, strategic research to use indigenous rock phosphate reserves, that are predominantly low-grade need to be initiated. These may include:

- Use of rock phosphate in making low-analysis phosphate fertilizers.
- Combining low grade and high grade rock phosphates and beneficiation and exploring the possibility of making high analysis P fertilizers.
- Direct use of rock phosphates in acid soils and under perennial and plantation crops.
- Exploring the possibility of using nano-sized rock phosphates.
- Use of nitrophosphates, phosphocompost and P solubilizing biofertilizers.

Although the benefits of P in agriculture are evident, it can be a pollutant if it moves from the site of application. The main concern is P transport from soils to streams, rivers, lakes, and eventually oceans. Phosphorus transported from agricultural soils can promote eutrophication, which is considered as one of the most pressing environmental problems. Loss of soil P to water bodies causes undesirable changes in the ecology of aquatic ecosystems, often with serious economic consequences. There is a problem of overuse and build up of P in pockets that lead to its inefficient use and consequent environmental pollution (Muralidharudu *et al* 2011). It is highly desirable to identify possible ways and means for the most efficient use of this invaluable plant nutrient. This should include finding agronomic and other technological solutions to use different sources of P in the most efficient manner but also finding future research areas that could make possible using sources of P that are now either uneconomical or current technology is not enough to make them usable. This has to also include finding practical ways to maximize P use efficiency by recycling phosphorus from solid waste and waste water systems, in cities, agriculture & industry and optimizing its spatial and temporal flows.

2. PHOSPHATE REACTIONS IN SOIL

Phosphorus occurs both in organic and inorganic forms in soils. It may be found in much low concentrations dissolved in the soil solution or associated with soil minerals or organic materials. The relative amount of each form of P varies greatly among soils, with the total amount in a clayey-textured soil being up to ten times higher than in a sandy soil.

A large number of compounds make up the organic P in soils, with the majority being of microbial origin. Organic P is held much tightly and is generally not available for plant uptake until the organic materials are decomposed and P is released via mineralization process. Mineralization is carried out by the microbes, and is affected by factors such as soil moisture, composition of the organic matter, oxygen concentration and pH.

The reverse process, immobilization, refers to the tie-up of plant-available P by soil minerals and microbes that use P for their own nutritional needs. Microbes may compete with plants for P, if the decomposing organic materials are high in carbon and low in nitrogen and phosphorus (i.e., wheat straw). Mineralization and immobilization occur simultaneously in soil. If the P content of the organic material is high enough to fulfill the requirements of the microbial population, then mineralization will be the dominant process.

The concentration of P in the soil solution, range from 10^{-4} M, much high, to 10^{-6} M, to 10^{-8} M in some poor tropical soils. Phosphorus in the inorganic form occurs mainly as aluminum, iron or calcium compounds. Solution P, active P and fixed P are the three main pools of P in soil. The solution P pool is much small, usually contains a fraction of a kg of P per hectare. The solution P is usually in the orthophosphate form, but small amounts of organic P may exist as well. A growing crop would quickly deplete P in the soluble P pool if the pool is not continuously replenished. The active P pool is P in the solid phase, that is relatively easily released to the soil solution. As plants take up phosphate, the concentration of phosphate in solution is decreased and some phosphate from the active P pool is released. Because the solution P pool is much small, the active P pool is the main source of available P for crops. The active P pool contains inorganic phosphate that is attached (or adsorbed) on active sites on the surfaces of soil particles. The fixed P pool of phosphate contains inorganic phosphate compounds (very insoluble) and organic compounds (resistant to mineralization by microorganisms in the soil). The inorganic phosphate compounds in fixed P pool are more crystalline in their structure and less soluble than those considered to be in active P pool. Some slow conversion between fixed P pool and active P pool always occurs in soils.

The chemistry of soil P is much complex, with more than 200 possible forms of P minerals being affected by a variety of physical, chemical and biological factors. Soluble P resulting from commercial fertilizer applications or from mineralization reacts with soil constituents to form P compounds of very low solubility (low plant availability). This series of reactions is commonly referred to as sorption or fixation. Iron and aluminum compounds will fix (tie-up) P under acidic conditions (soil pH < 6), while, under alkaline conditions (soil pH > 7), phosphorus is preferentially fixed by calcium and magnesium compounds.

Phosphorus availability to plants in most soils is greatest when soil pH is in the range of 6 to 7. Application of liming materials is a common production practice to raise the pH in acidic soils to make P more available. However, lowering the pH of calcareous soils to increase the solubility of P is not an economically viable option, since large amounts of acidifying material are typically needed. Thus, soils with high pH generally have P fertilizer applied every year immediately before sowing the crop.

Soils that have not received P fertilization for a few years can render much of the P fertilizer applied unavailable. Thus, it is best to maintain proper P fertilization of soils and not to mine those of their native P. Otherwise the soil may fix P until the P mineral fractions in the soil have been replenished through proper P fertilization practices.

Soil P-Cycle: The P cycle in the soil includes inputs and outputs of P, as well as internal cycling of P. Removal of P can occur by erosion of enriched sediment, desorption by moving water (runoff, leaching, tiles), or crop and animal removal. The major internal P inputs are weathering and the major external P inputs to the soil include fertilizers, agricultural wastes, plant residues, atmospheric deposition, and municipal/industrial by products. Finally, the internal cycling processes include immobilization-mineralization, adsorption-desorption, and precipitation-dissolution (Zaimes and Schultz, 2002).

The organic P content of soil varies from traces in arid regions to several hundred ppm in thick forest soils. Often, nearly half of the total P in soil occurs in organic forms, most of which are derived from plant residues and, in part, acquired by soil organisms from inorganic sources. The soil organic P compound can be generally classified into three groups, namely, inositol phosphates, nucleic acids, and phospholipids. In soils, the application of wastes as organic fertilizers, allows to reincorporate nutrients to the biogeochemical cycles. The important factors that influence the bioavailability of P in soils amended with organic wastes are the soil solution pH, adsorption reactions, organic matter, phosphatase activity and low molecular weight organic acids.

3. EFFICIENT UTILIZATION OF P: KNOWN TECHNOLOGIES

Management of P is strongly interlinked with soil characteristics such as soil reaction, degree of weathering, the amount and nature of clay minerals, organic matter content and water regime. The extent of initial P adsorption in soil and the subsequent slow reaction rate, in addition to cropping intensity and cropping patterns should also be considered, when planning for P management practices.

Management of P fertilizers should aim to maintain a enough available-P level in soil solution at the appropriate time at a reasonable cost, thus increasing P use efficiency in crop production. These may be achieved by using a suitable P source for a given soil-crop situation to minimize reactions with soil component that render P in soil solution unavailable to crop, modifying the soil component or application method (of P fertilizer) to reduce the amount of P in the solid phase; and selecting a P application timing that will prevent a marked rise and fall of P concentration in soil solution.

Some good P management practices and the conditions under which they are suitable are given in Table 2. Some specific P best management practices (BMPs) particular to cropping systems are given in Table 3. These BMPs are based on nutrient requirement of individual crops, the extent of response of crops to a particular fertilizer nutrient, and the capacity of crops to utilize the residual fractions of soil nutrients. Maintenance of good earthworm population in soils is also very beneficial for soils since they help in enhancing P availability in soils. Method of P application has a profound impact on P use efficiency. It is found that deep placed P + restricted irrigation is on par with P broadcast + unrestricted irrigation. It is most efficient when P is banded with or near the seed. Band placement reduces surface contact between the soil and fertilizer. Seed placed P is most beneficial when soil test P is low and soil moisture is optimum.

4. MANAGEMENT AND TECHNOLOGICAL OPTIONS

Efficient use of soluble fertilizers

Maintaining the critical level of plant-available P and prevention of environmental pollution is the most effective way to increase the use efficiency of soluble P fertilizer and should receive utmost priority. Also, best P management practices, machinery for the right placement of P along-with seed, precision application based on yield zoning, developing new innovative controlled/slow release P fertilizers, and nano-fertilizers need to be promoted. A synergy or combination of right fertilizer, placement, organics and efficient cultivars would do wonders in improving P use efficiency.

Direct use of low grade Indian rock phosphates

- Use of carbonate-apatite (francolites) rock phosphates of sedimentary origin in acid soils, submerged rice soils and plantation crops.
- Promotion of phospho-compost in neutral and slightly alkaline soils.
- Partially acidulated rock phosphates and compacted rock phosphate along with water soluble phosphate in some soil-crop-situations especially in oilseeds and pulses growing areas need attention.
- Since Indian rock phosphates predominantly are of low grades, low cost beneficiation techniques need to be developed for both direct use and also for P fertilizer manufacture.

Table 2. Some best P management practices

Management Practices	Situation/Condition
Phosphorus broadcast	Under high speed operations and heavy application rates
Phosphorus placement	In low soil test P where early season stress is likely as in high P fixing soils
Fertigation	Good under intensive agriculture; Increases P fertilizer efficiency; Protects environment; Sustains irrigated agriculture
Use treated rock phosphate	Incubation with organic matter; Addition of P solubilizer, *A. awamori,* during composting
Increasing the effective rooting area	Root symbiosis with *Arbuscular mycorrhizal* fungi (AMF)
Increase P availability through rhizosphere modification	Root exudates: phosphatase, oxalates (genotypic differences)
Use of earthworms	Enhance nutrient availability mainly in tropical soils through casting
Organic residue amendments	A rise in pH in acid soils accompanied by P solubilization; Production and release of organic anions; Increased enzymatic activity; Complexation of exchangeable ions such as Al^{3+}, Fe^{3+}

Subba Rao and Srivastava (2012)

Table 3. Nutrient BMPs in some cropping systems in India

Cropping sequence	Strategy
Rice-wheat, Pearl millet-wheat, soybean-wheat	Apply phosphorus to winter (*rabi*) wheat and skip P application to *kharif* crops
Maize-wheat, Sorghum-wheat	Prefer to apply P to wheat
Gram-rice	Apply superphosphate to gram and harness the residual effect on rice
Sorghum-castor	Apply P at recommended dose to sorghum and castor crop may be given a reduced dose
Potato based System	P should be applied to potatoes in a potato based cropping system
Groundnut-wheat	Apply recommended dose of P to wheat and skip application to groundnut

Acharya et al., (2003)

Use of crop residues and organic manures

Managing crop residues in conservation agriculture and farmyard manure in dry-land areas may not only supplement P but also help in better utilization of fertilizer P. Integrated P supply systems involving fertilizer, manure, legume crop in the rotation, and P solubilizing organisms synergistically provide not only P nutrition but also help to attain higher P use efficiency.

Microbiological mobilization of insoluble P in the rhizosphere

- Use of consortia of useful phosphate solubilizing/ mobilizing microorganisms consisting of *Trichoderma, Pseudomonas,* and *Arbuscular-mycorrhizal* (AM) fungi may help in enhancing P use efficiency on crops and cropping systems. Another important group of organism for P solubilization is phosphatase and phytase producing fungi (PPF). More emphasis needs to be given to field level testing of these microbes, creation of awareness among the farmers, and availability of bio-fertilizers at affordable prices. There is also need for developing easily maneuverable and accessible inocula of AM fungi for use in field crops.

- There is a need to strengthen the selection criteria for high P efficiency in different crop cultivars. Modern breeding tools need to be exploited to develop such genotypes. Genes for efficient P acquisition and utilization need to be identified and used in breeding programmes.

Recovering phosphorus from solid and liquid waste

Human and animal urine, sewage water and sludge in urban areas are rich sources of P that need to be tapped with appropriate economically viable engineering and technologies. There is need for linking animals and agricultural production systems for efficient P recycling.

Reducing P losses from soil-plant-animal systems

Integration of P flows through spatial integration of livestock and arable agriculture and also following best technological options for minimizing P losses from soils such as reduced tillage, buffer strips, and cover crops are urgently required. There is need for improvement in existing soil test methods and interpretative tools for P for combining quantity, intensity and buffer capacity parameters and also including the contribution of organic P pool and subsoil P.

5. POLICY OPTIONS

- Government should include efficient P use in the promotion of best management practices (BMPs). In doing so, strong and reliable soil testing mechanism is to be developed. Frequent interactions among State Agril. Universities (SAUs), ICAR etc. are required. The right type of fertilizer in different agro ecological conditions and its availability during the crop season has to be ensured. Also the development of fertilizer grades incorporating P as customized fertilizer as well as liquid fertilizer.

- Placement is essential, but enabling systems are needed such as farm implements and machinery for placement especially in intercropping systems.

- Greater emphasis is needed to improve field level efficiency of PSB, VAM etc. particularly in soils of different pH. Creating awareness and doorstep availability of biofertilizers at an affordable price will popularize their use.

- To use low grade rock-phosphates, a new policy is required for the direct use of indigenous reactive rock phosphates under certain soil and crop conditions and also explores new resources in the country.

- The modified RP products include partially acidulated RPs, SSP-RP mixture, Pyrite-RP mixtures, PSB-RP mixtures, compacted RPs etc., which are found as good as water soluble P fertilizers and economical in a variety of crops. But unlike other countries such as Australia, USA, China, New Zealand, Brazil, Cuba etc, these are not available in Indian markets and are not popular among the farmers.

- There is an urgent need for popularizing phosphor-composting technology. Making low grade RPs available to composting plants and to the farmers at cheaper price is the need of the hour.

- There should be a technical discussion within the Researcher - Fertilizer Industry-Policy makers-Extension agency interface, so that bottlenecks of non-availability of rock phosphate in the market could be discussed and efforts should be made to overcome them.

- Residue recycling is an alternative way for improving nutrient use efficiency. To maximize recycling of organic wastes/residues from all possible sources, diversion to other sectors need to be restricted. The incentive is needed for encouraging residue recycling and against crop residue burning.

- There is a need to develop linkages with those involved in the processing of these wastes for other purposes and those who use these as sources of organic matter and nutrients in agricultural production, considering soil, food quality and human health linkages.

- The Indian Govt. should provide loans to fund programmes focusing on phosphate recycling especially in big urban areas. There is also a great need for private initiatives.

- Currently, many specialty water soluble fertilizers suitable for fertigation, and foliar application have been introduced in the market and are increasingly becoming popular among the farmers particularly in rain-fed/dry land areas. There should be a regulatory body to look over these materials about their quality/composition, crop/stage specificity, rate and mode of application, their efficiency in comparison to routine water soluble fertilizers.

6. RESEARCH NEEDS

- Research on reducing phosphate fertilization, specifically on phosphate-accumulated soils must become a priority. In future, the P in such enriched soils can possibly be "mined" through biological mobilization.

- Some research issues that need attention are accounts of residual P in cropping systems especially in the long term, and developing techniques of the biological mobilization of insoluble/sparingly soluble P in the rhizosphere.

- Efficient waste recycling is an integral part of P supply in agricultural production systems. At the national level strong emphasis must be placed on further development of recovery and recycling technologies for manure, municipal solid waste, sewage sludge, and other biomass residues, reducing the polluting effects of P runoff into water bodies.

- Developing precision P placement techniques, strategy of heavy initial application of rock phosphate P, use of nano-rock phosphates, and state-of-art controlled release P fertilizers need be explored.

- There is a need to strengthen the selection criteria for high P efficiency in different crop varieties. Modern breeding tools can be of great help to develop such genotypes for high P use efficiency. Breeding efforts will definitely lead to the identification and development of P-utilization and P-acquisition efficient genotypes.

- In rain-fed areas, application of P fertilizers to different crops as basal application are often found risky owing to failure of crops at later stages owing to long dry spells. Thus need is to develop suitable strategies for P management in rain-fed crops.

- Role of chemically and biologically synthesized nano-phosphorus in enhancing the release of enzymes and organic acids for better mobilization of native soil P and higher P use efficiency need be studied .

- Further research must concentrate on developing a better understanding of P transport from agricultural sources through non point source pathways. These studies should be conducted at large scale (small catchment, watershed) and over wide ranges of regions that are diverse and under different combination of BMPs.

7. ACTION POINTS FOR IMPLEMENTATION

Improving phosphorus use efficiency in crop production

- Lot of awareness need to go among farming communities for modifying P fertilizer applications through State Agriculture Departments, ATMA, and Watershed programmes in terms of monitoring soil fertility programme on a regular basis. In general, delineation of actual areas with high available P need be given top priority.

- Develop and implement the '4R nutrient management' i.e., right fertilizer, right amount (soil test based), right time of application (crop growth stage) and right application method (band placement) and precision application based on management zones.

- About 250 cropping systems are being practiced in India, so one may prepare a blueprint of the P requirement of at least 25-30 most important cropping systems (which occupy a significant area and considered important from the food security point of view). The application of P on the basis of cropping sequence instead of individual crop needs to be taken into consideration for improving P use efficiency by taking advantage of naturally occurring nutrient mobilization.

- Reduce nutrient losses through site-specific mitigation measures, including erosion control measures, cover crops, buffer strips, tillage management and BMPs for fertilizer and manure applications.

- Phosphorus inputs through fertilizers, feed and manures need be balanced with outputs at the farm gate through crop and animal produce or nutrient balance at the watershed level by maintaining the soil P level (through soil tests) and reducing transport of P through erosion and runoff.

- In large tracts of North-East Ecosystems with strong acid soils, and P fixation, and low productivity levels, promotion of right P fertilizers in these areas need lots of attention and caution.

- Breeding of P efficient genotypes of crops could be the cheapest and the most sustainable approach to addressing the foreseen non availability of phosphate fertilizers in enough amount is future.
- Some variations in soil fertility maps of same area prepared by different agencies are noted due to differences in methods and critical limits. There should be a map reconciliation system to minimize the variations in maps to serve the purpose of planning P resources at the district level to the desired extent.

Improving phosphorus use efficiency in animal production

- Over-application of manures to cropland in some intensively cultivated areas over the past few decades has increased the saturation of soils with P to the point that P losses in surface flow and leaching are now serious concerns.
- Improving fertilizer value by reducing losses requires research and policies to minimizing losses from animal housing, manure storage and handling, manure treatment, and from land application of manure.
- Improving fertilizer value of manure processing involves the production and use of value added/enriched manures, thus increasing their fertilizer value.

Improving phosphorus efficiency in fertilizer and food supply & reducing food waste

This would require

- Reducing waste from phosphorus mining and processing
- Improving food supply efficiency and reducing food waste
- Initiate research to determine how production, processing and consumption of food could be streamlined into an integrated strategy to maximize the re-use of P whilst minimizing energy consumption.

Recycling phosphorus from waste water systems, in cities, agriculture & industry

- In India the most of the population is living in villages where directly or indirectly sewage is going into agricultural systems. In cities, municipal waste water is treated through several stages of water treatment; however, in many cities and towns, a well-developed sewage treatment system is still missing. One of the greatest challenges is redesigning and upgrading an existing sewage system to capture the P from swage/waste waters.

ž Develop a concerted set of economic incentives and regulatory measures directed at the reduction of phosphorus losses per unit area and per unit produce, and the promotion of optimized re-use of phosphorus recovered from 'wastes'.

Optimization of phosphorus flows and limiting losses

ž Better nutrient cycling is achieved on most agriculture-livestock connected farms, as crop residue or manure nutrients produced by animal feed crops grown on the farm. In general larger amounts of nutrients are exported off the farm in vegetation (grain, forages and vegetables etc.) than in animal products. Nutrient balance cannot easily be achieved on either a crop taken with external nutrient inputs or a livestock farm that depends significantly on imported feeds. In the above cases, either nutrients in the crop residues or manure accumulates on the soil leading to environmental consequences.

ž Agricultural P inputs to surface water have increased because of intensive livestock grazing and the combined manure and fertilizer inputs in excess of crop requirement that led to a build-up of soil P levels. Because, several factors influence P inputs, need is to understand and identify agricultural P sources pathways and processes that control P transport and their influence on P availability and their potential impact on surface water P quality.

The source and transport controls should be targeted to identify intensively fertilized areas of P export from watershed. Threshold soil P levels that guide manure applications should be linked with site vulnerability to P loss.

General

ž Establish a representative and global platform representing all key stakeholders dealing with phosphorus in different parts of the food system, to facilitate an effective governance of phosphorus, given the uneven distribution of supply and demand in space and time.

ž Promote independent assessments of long-term phosphorus supplies and demand, taking into account available techniques, population size and alternative consumption patterns, to identify solutions and adapt these to local conditions and requirements.

- Raise public awareness of the scarcity of phosphate rock, whilst presenting policy options and measures showing a way out of the problem.

8. EPILOGUE

Soil P is a finite, non-renewable and limited resource. Continuous supply of P through manures and fertilizers is indispensable for crop production sustenance. About 95% of the phosphate rock mined is used to produce fertilizers. The supply of phosphate rock is expected to decrease year upon year, constrained by economic and energy costs. The approaches of P management may be different in P rich soils and in P poor soils. The approach "P bank in soil" is more applicable to P rich soils with intensive farming for sustaining environmental quality, whereas an alternative approach of the use of low cost P sources such as phosphate rock and manures may play important role in managing phosphorus in P poor soils. Continuous application of P at higher rates to different crops may cause P pollution on one hand and escalating prices of P fertilizer in the recent past may reduce the profitability of the farmers on the other hand. Enhancing use efficiency of applied P in different crops/cropping systems would be an economically viable and environmentally benign way of efficient P management. The P use efficiency could be enhanced by utilization of insoluble P sources such as phosphate-rock, mobilization of unavailable pools of P in the soil through a selection of crops with the efficient root system, cropping system based P application, and integration of mycorrhizae, earthworms and P solubilizing bacteria etc. Sustainable phosphorus use will require an integrated approach that combines efficiency and reuse, to reduce current phosphorus losses, minimize environmental impacts, conserve a finite resource and ensure that all the farmers have access to phosphorus. Improving the efficiency of phosphorus use will buy the time needed to implement more fundamental sustainable phosphorus use measures. Improvements in efficiency can be achieved by reducing losses in mining, fertilizer production and in agriculture. It may also come from changing the ways we handle wastes containing P in processing industries, and in the way we use phosphorus in our households and specialized waste-treatment installations.

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