

## MANAGEMENT PRACTICES FOR ENHANCING FERTILIZER USE EFFICIENCY UNDER RICE-WHEAT CROPPING SYSTEM IN THE INDO-GANGETIC PLAINS

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### ABSTRACT

Rice and wheat are the staple foods for almost the entire Asian population and therefore they occupy a premium position among all food commodities. The era of the Green Revolution started during the early 1970s with wheat and rice and since then the rice-wheat cropping system of the Indo-Gangetic Plains has played a significant role in the food security of the region. However, recent years have witnessed a significant slowdown in the yield growth rate of this system and the sustainability of this important cropping system is at risk due to second-generation technology problems and mounting pressure on natural resources. Traditional cultivars and conventional agronomic practices are no longer able to even maintain the gains in productivity achieved during the past few decades. Demand for food is increasing with the increasing population and purchasing power of consumers. The rice-wheat cropping system is labour-water-and energy-intensive and it becomes less profitable as these resources become increasingly scarce and the problem is aggravated with deterioration of soil health, the emergence of new weeds, and emerging challenges of climate change. Therefore, a paradigm shift is required for enhancing the system's productivity and sustainability. The 4R Principles of applying right source of nutrients, at the right rate, at the right time and at the right place is expected to increase nutrient use efficiency, productivity and farm profit in rice-wheat cropping system production and provides opportunity for better environmental stewardship of nutrients.

**Keywords:** Best Management Practices, Cropping system, Indo-Gangetic Plains, Sustainability.

### INTRODUCTION

Rice and wheat crops have been grown in South Asia (India, Pakistan, Nepal, Bangladesh, and Bhutan) and China for more than 1000 years. The rice wheat (RW) cropping system that is, growing these crops in a sequence in an annual rotation, has been developed through the introduction of rice in the traditional wheat-growing areas and vice versa (Paroda et al., 1994; Tran and Marathe, 1994). This cropping system is one of the world's largest agricultural production systems, covering an area of 26 million hectares (Mha) spread over the Indo-Gangetic Plains (IGP) in South Asia and China. It accounts for about one-third of the area of both rice and wheat in South Asia and produces staple food for more than 20% of the world population. The RW system now comprises about 13 Mha in area in the IGP, of which the Indian part of the IGP comprises about 10 Mha. More than 85% of the RW system practiced in South Asia is located in the IGP. About one-third and one-half of the total cereals of India and Pakistan, respectively, are produced in this region. In India, the IGP cover about 20% of the total geographical area (329 Mha) and about 27% of the net cultivated area, and produce about 50% of the total food consumed in the country (Dhillon et al., 2010). The IGP, spread from the Indus basin in Pakistan Punjab in the west, passing through India and Nepal to the Brahmaputra floodplains in Bangladesh in the east, are the most important agricultural regions of the Indian subcontinent. The IGP comprise (i) the Trans IGP (Punjab in Pakistan, and Punjab and Haryana in India), (ii) Upper and Middle IGP (western, central, and eastern Uttar Pradesh and Bihar), (iii) Terai (an extension of the IGP) in Uttarakhand in India and parts of Nepal, and (iv) Lower IGP (West Bengal in India and parts of Bangladesh). In Pakistan, the RW cropping system occupies about 10% of the total cultivated area (2.1 Mha), mainly in two zones, the Punjab RW zone, comprising about 1.2 Mha, and the Sindh RW zone, occupying the remaining area (Aslam, 1998).

The Indian portion of the IGP comprises Punjab, Haryana, Uttarakhand, western and eastern Uttar Pradesh, Bihar, and West Bengal. These plains are believed to be formed by alluvium soil brought from the Himalayas by the Indus and Ganges river systems about 7000 years ago (Palet et al., 2009). Except for a strip of the

Shivalik hills, alongside its eastern border, the entire area is flat alluvial plain at 180e290 m above mean sea level. The soils of the plains region are generally deep alluvium, sandy loam to loam in texture, having moderate water- holding capacity, alkaline in reaction, and poor in organic matter content. In the plains of the Indus and Ganges between west and east, there is a gradual transition in physiography, climate, natural vegetation, and cropping patterns. Alluvial soils deposited by the river systems are highly fertile and underlain by extensive aquifers resulting in the development of an extensive groundwater network for irrigation. The rice and wheat crops have become so important for this region that rapid expansion of a tube well network in the northwest (NW) part of the IGP has led to the exploitation of even poor-quality groundwater aquifers for irrigation. Until the mid-1960s, rice cultivation in some pockets of the IGP was restricted to basmati rice (tall-statured aromatic rice with good cooking quality) having low productivity of about 1 t ha (Kumar and Nagarajan, 2004). The introduction of dwarf wheat cultivars (Sonora 64 and Lerma Rojo) from Mexico, which required lower temperature for germination and tillering, led to a shift in the sowing time of wheat from mid-October to late October/early November, allowing the cultivation of kharif (rainy season) crops of longer duration. This provided an opportunity for the cultivation of input-responsive, high-yielding dwarf cultivars of rice in the non-traditional areas of the IGP. In the subsequent years, rice and wheat in these areas replaced the less remunerative coarse cereals and more risk-prone oilseed and pulse crops. The Green Revolution technologies led to the emergence of RW as the major cropping system in the IGP, which now ranks first among the 30 major cropping systems identified in India (Das, 2006). In the Trans and Western parts of the Upper Gangetic Plains, rice (indica- type monsoon rice)-wheat (spring) is the main cropping system, whereas rice-wheat-mung bean/cowpea/jute in the eastern part of the Upper Gangetic Plains and in the Middle and Lower Gangetic Plains and the rice-rice-wheat cropping system in the Nepal Terai region are predominantly followed.

After the mid-1960s, a substantial increase in area under rice and wheat took place in NW India, particularly in Punjab and Haryana states, despite semi-arid climatic conditions. These two states

constitute a highly productive RW zone in the IGP contributing about 69% of the total food output in the country (about 84% wheat and 54% rice) and this region is called the "food bowl of India". This region has played a vital role in sustaining the food security of India by contributing about 40% of wheat and 30% of rice to the central stock of India every year during the last four decades (Hira and Khera, 2000). Average combined yields of rice and wheat in the RW system in the IGP area are 5-7 t ha<sup>-1</sup> while yields of 8-10 t ha<sup>-1</sup> are attained with greater fertilizer application and the adoption of better agronomic practices (Timsina and Connor, 2001).

The soils of the IGP region have developed from alluvium brought from the Himalayas by the Indus River system. Soil moisture regimes are udic, ustic, and aridic, whereas the soil temperature regime is mainly hyper-thermic. Soils under the RW system in the IGP, especially in the NW, Bhagirath S. Chauhan et al. are porous, coarse, and highly permeable and are being used for raising upland crops as well as wetland rice (Aulakh and Bijay-Singh, 1997).

Groundwater and rainfall are the major water resources. Mean annual rainfall in Punjab, Haryana, and Uttar Pradesh plus Uttarakhand is 61, 56, and 84 cm, respectively, with a coefficient of variation often exceeding 20% (Parthasarthy et al., 1987). NW India and Bangladesh are perhaps the only regions in the world where groundwater is used for rice (mainly transplanted) cultivation. Of the net cultivated area, 97% of the area in Punjab, 83% in Haryana, and 68% in Uttar Pradesh is irrigated.

#### PROBLEMS IN RICE-WHEAT CROPPING SYSTEM IN THE INDO-GANGETIC PLAINS OF THE INDIAN SUBCONTINENT

The spread of the RW system has brought forth several edaphic, environmental, and social implications. A number of problems have cropped up in the region with the cultivation of rice and wheat in a system mode for the last four decades, threatening the sustainability of the system. The NW IGP region has paid a heavy price to earn the status of food bowl. Evidence is accumulating that the RW system is now showing signs of fatigue and yields of rice and wheat in this region have reached a plateau or are declining, the soils have deteriorated, the groundwater table is receding at an alarming rate, total factor productivity or input-use efficiency is decreasing, cultivation costs are increasing, profit margins are decreasing, and the simple agronomic practices that revolutionized RW cultivation in the IGP are fast losing relevance (Hobbs and Morris, 1996). In India, rice production and productivity that increased at an annual compound growth rate of 3.62% and 3.19%, respectively, in the 1980s, declined to 1.61% and 1.34%, respectively, in the 1990s. During the same period, wheat productivity declined from 3.10% to 2.32%. This declining rate of production has posed serious challenges before the nation to produce enough food for the increasing population and has raised some doubts about sustaining the productivity gains of rice and wheat in the region (Paroda et al., 1994). The major factors that have stalled the productivity of the Rice Wheat system are (i) Over exploitation of groundwater resources leading to a decline in the groundwater table (Hira, 2009; Hira et al., 2004; Humphreys et al., 2010), increased energy cost of pumping water, and deterioration of groundwater quality; (ii) declining soil organic matter and increasing multiple deficiencies of major nutrients (N, P, K, and S) and micronutrients (Zn, Fe, and Mn) due to their over mining from soils (Ladha et al., 2000; Tiwari, 2002); (iii) increasing salinity (Tiwari et al., 2009); (iv) the development of herbicide resistance and a shift in weed flora and pest populations (Hobbs et al., 1997); and (v) poor management of crop residues, leading to their burning. The situation in the Pakistan Punjab is similar to that of the Indian Punjab, where water logging, soil salinity and sodicity, inadequate and unreliable water supplies, poor-quality underground water for irrigation, and inadequate drainage are the major constraints (Aslam, 1998). These problems are expected to be further aggravated unless interventions are made soon. Judicious use of fertilizers and water will determine the sustainability of RW and future food security of the IGP. About a decade ago, some challenges confronting the productivity and management of the RW system were described (Timsina and Connor, 2001). Since then, several new developments have occurred. In this article, the problems confronting the productivity of rice and wheat in the RW system are

updated and discussed and efforts are made to suggest technological innovations to overcome these problems to sustain the productivity of these crops in the region.

#### TECHNOLOGICAL OPTIONS FOR IMPROVING FERTILIZER USE EFFICIENCY UNDER RICE-WHEAT CROPPING SYSTEM

Introduction of high yielding varieties (HYVs) coupled with expansion of irrigation facilities, and increased use of chemical fertilizers and other agro-chemicals have brought about spectacular increases in the yield of crops, particularly rice and wheat. About half of the total increase in food grain era has been attributed to the use of fertilizers and more than one-third of this increase is due to N fertilizers alone. Inefficient inputs/fertilizer use is a key factor pushing the cost of cultivation and pulling down the profitability in farming. Total factor productivity (TFP) is used as an important measure to evaluate the performance of a production system and its declining trend is a serious issue. A fatigue in the ratio between the inputs and output is indicative of TFP deceleration with concomitant un-sustainability of crop productivity. The challenge is how to increase food production in the country by around 60 per cent over next two decades without jeopardizing the soil and water resources which are already under great stress. With increased demand for cereals, pulses and cooking oil, the productivity per hectare or unit input is decreasing. Thus the risks of degradation of natural resources (soil and water) are increasing because of extractive farming practices (Conklin Jr. and Stilwell, 2007).

#### TECHNOLOGIES ADOPTING INCREASING NITROGEN (N) USE EFFICIENCY

Nitrogen use efficiency is often expressed in terms of agronomic efficiency (kg grain/kg N applied), physiological efficiency (kg grain/kg N taken by crop), chemical efficiency or apparent recovery (per cent of applied N taken by the crop), efficiency ratio (kg grain/kg N uptake, without considering unfertilized control), and also sometimes as partial factor productivity (kg grain/kg N applied without considering unfertilized control). The NUE is thus a function of soil to supply adequate amount of N, and ability of plant to acquire, transport in root and shoot, and to remobilize to other parts of the plant. Use efficiency of applied N as estimated by the difference in N uptake of the above-ground portions of N fertilized and unfertilized plots, and expressed as percentage of N fertilizer applied to the crop is only about 30 to 40 per cent. The P efficiency ranges from 20-40 per cent only. Hence, there is urgent need to increase nutrient use efficiency from the view point of costs and water quality concerns.

There have also been genuine concerns over nutrient use efficiency, in general, and N use efficiency (NUE) in particular, for economic as well as environmental reasons. Worldwide, NUE for cereal production is as low as 33 per cent. The unaccounted 67 per cent represents an annual loss of N fertilizer worth up to Rs. 72,000 cores (NAAS 2005). The manufacture of nitrogenous fertilizers involves huge amounts of foreign exchange and consumes large quantities of non-renewable energy resources such as naphtha, natural gas, coal etc. Poor utilization of fertilizer N by plants also adds to the pressure on these finite resources. Low NUE for crops implies higher costs to producers and consumers and, therefore, reduced competitiveness. Loss of N from soil plant system results from gaseous plant emission, nitrification, de-nitrification, surface runoff, volatilization and leaching beyond rooting 15 zones of crops. Many N recovery experiments conducted in the country on different crops have reported unaccounted losses of fertilizer N from 20 to 50 per cent depending on the local conditions. These losses of fertilizer N, or in general, the leakages of the reactive N from the agricultural systems into the environment are a cause of serious concern. Nitrogen on its own rarely increases yield much and for long; other nutrients, water, crop variety, weed and pest control must all be in proper proportion and available before fertilizer N can do its best. Harvesting high yields by applying only N is at best a short-lived phenomenon, as was shown in the early years of the green revolution. Clearly "N-driven systems" are not sustainable, as N becomes a 'shovel' to mine the soil of other nutrients, with the result that soils initially well supplied in other nutrients become deficient in them and productivity declines. Researchers have shown that the production practices that have

resulted in increased N use efficiency relative to conventional or standard practices are those that will counter conditions or environments that contribute to N loss from soil-plant systems. The challenge is to make such modern farming systems accessible and affordable to the farmers, who are constantly under pressure to cut input costs (NAAS 2005). The cause for low Nitrogen Use Efficiency and declining response to N fertilizers under Rice- Wheat cropping system can be grouped as follows (NAAS 2005):

#### **Nutrient supply and soil fertility**

Susceptibility of N fertilizers to losses by various mechanisms  
 Imbalanced use of N fertilizers  
 Poor management for secondary and micronutrients, especially S, Zn, Mn, Fe and B  
 Use of high analysis fertilizers like urea and di-ammonium phosphate (DAP) and inadequate addition of organic manures  
 Inappropriate rate, time and method of application  
 Low status of soil organic carbon and soil degradation due to high salinity, sodicity, acidity, water logging and having adverse effect on below-ground biodiversity, especially of agriculturally-important micro-organisms.

#### **Agronomic practices**

Delayed sowings/plantings  
 Low seed rate resulting in poor crop stands  
 Poor weed management especially in Rice field  
 Inefficient irrigation and rainwater management  
 Large scale monoculture and non-inclusion of legumes in cropping systems  
 Lack of consideration of previous cropping in the same field  
 Inadequate plant protection  
 Non-availability of seeds of HYVs at affordable price and at the appropriate time  
 Lack of more efficient N using genotypes (both in case of Rice and Wheat cultivars)

The suggested approaches to minimize N losses and increase use efficiency include the following option (Roy and Pederson 1992)

Identification of the most suitable fertilizer material  
 Manipulation of the application techniques including split application and placement  
 Manipulation of particle size, use of coating materials and other chemicals  
 Judicious and economical application of fertilizers for synergistic interactions  
 Application of organic sources along with mineral fertilizers  
 Efficient agronomic management practices such as tillage, irrigation, mulching, weed control, plant population and use of varieties with higher NUE.

Efficient input use can be achieved by assessment of available inputs and conservation against possible losses, integrated use of inputs in a synergistic manner, optimal allocation of inputs among the competing demands to achieve maximum return, maximizing input use efficiency by developing suitable site specific technologies.

#### **Efficient nutrient management**

Nutrient plays a key role in increasing agricultural production through intensive cropping. Sustainable agriculture can be achieved by efficient utilization of this costly input. Nutrient use efficiency can be improved by checking the path ways of nutrient losses from soil-plant system, making integrated set of nutrients from all possible sources, optimal allocation of nutrients to crops and maximizing the utilization of applied and native nutrients by the crops.

#### **Checking the pathways of nutrient losses**

Nutrient present in soil and added through fertilizers and manures are lost by gaseous loss, leaching loss, runoff/erosion losses and fixation in soil. Efficient nutrient management demands understanding the pathways of nutrient losses and developing

technologies to minimize these losses.

#### **Reducing gaseous loss**

Part of the applied N is lost from soil by volatilization of ammonia and part of the nitrogen is lost as  $N_2O$  and  $N_2$  gas by de-nitrification. Volatilization loss of ammonia can be minimized by mixing of nitrogen fertilizers in soil rather than broadcasting on soil surface, deep placement of urea super granules (USG) in puddle rice field, using urease inhibitors like thiourea, methyl urea, caprylohydroxamic acid, phenyl phosphorodiamidate (PPD), ammonium thio-sulphate etc. and adding inorganic salts of Ca, Mg or K with urea. Some coated material like sulphur coated urea (SCU), gypsum coated urea (GCU), plastic coated urea (PCU), mud ball urea and synthetic slow release urea based fertilizers viz., isobutylidene diurea (IBDU) and crotylidene diurea (CDU) etc. may be used to retard the rate of urea hydrolysis and thereby, reducing ammonia volatilization. Nitrous oxide ( $N_2O$ ) is mainly produced by denitrification of  $NO_3^-$  under anaerobic condition, as in lowland rice fields. Nitrous oxide is one of the greenhouse gases that are believed to be forcing global climate change. Denitrification loss can be minimized by avoiding the use of  $NO_3^-$ —form of nitrogenous fertilizer (e.g. calcium ammonium nitrate, potassium nitrate etc.) in rice and use of nitrification inhibitors viz., Dicyandiamide (DCD), N-serve (2-Chloro, 6-Chloro methyl pyridine), AM (2-Amino, 4-Chloro, 6-methyl pyrimidine), coated calcium carbide (CCC), neem-coated urea, deep placement of urea sugar granules (USG) in flooded rice field and efficient and efficient water management.

#### **Reducing leaching loss**

Mobile nutrients (e.g.  $NO_3^-$ ) are lost from the soil-plant system with the percolating water. Besides reducing the nutrient may pollute the groundwater. The groundwater having more than 10 mg  $NO_3^-$ , N per liter is unfit for drinking purpose (WHO). Leaching loss of  $NO_3^-$  can be minimized by balanced fertilization, split application of urea synchronizing with crop demand, manipulation of water application and rooting depth, appropriate crop rotations and use of slow release fertilizers and nitrification inhibitors like N-serve, DCD, AM, CCC and neem-coated urea.

Despite the success of synthetic nitrification and urease inhibitors in research farms they have poor acceptability among farmers because of high cost. However, the use of products plants like neem for coating urea can be popularized among the farmers to affect N economy and minimize long-term environmental consequences of denitrification and nitrate leaching.

#### **Reducing runoff and erosion losses**

Many water-soluble nutrients are lost through runoff. This loss can be minimized by proper crops land management and selection of proper crops and cropping systems, tillage and mulching. Nutrients sorbed on the surface of soil particles-clays and silts and soil organic matter are lost when the top soil is eroded by water or wind. Proper soil conservation measures should be adopted to minimize this loss.

#### **Reducing fixation of nutrients in soil**

In acid soils phosphorus is fixed as  $Fe^{++}$  and  $Al^{+++}$  phosphates and in neutral and calcareous soils it gets fixed as  $Ca^{++}$  phosphate. The availability of these fixed phosphates is very low. Phosphate-fixation in acid soil can be reduced by combined application of rock phosphate and single super phosphate and liming of acid soils. In both acid and calcareous soils phosphorus-fixation can be minimized by band placement of phosphatic fertilizers along with crop rows. Use of rock phosphate along with acid forming materials like pyrites or phosphate-solubilizing micro-organisms help in solubilizing of sparingly soluble rocks. Vesicular-arbuscular mycorrhizal (VAM) fungi are helpful in mobilizing both applied and native P reserves.  $K^+$  and  $NH_4^+$  ions are also fixed in the interlayer of 2:1 clay minerals like illite, vermiculite etc. nutrients fixed on soil-plant system but are not available to the crop in a short-term period. However, these are released at later stages of crop growth.

### **Integrated plant nutrient system (IPNS)**

The high cost of fertilizers coupled with relatively greater losses of fertilizer N leading to environmental pollution and yield decline over the year's calls for a cheaper and more sustainable measure to improve productivity by substituting part of the inorganic fertilizers by organic sources of nutrients. Organic sources of nutrients alone cannot sustain the crop yield at higher level to meet the demand of growing population. There is need to combine the use of inorganic fertilizers and organic sources of nutrients viz., manures, green manures, crop residues, biofertilizers etc. in a synergistic manner, which is referred as Integrated Plant Nutrient Supply (IPNS) System.

Integrated nutrient supply system sustains and improves the physical, chemical and biological health of soil and enhances the availability of both applied and native soil nutrients during growing season of the crops. This helps in retarding soil degradation and deterioration of water and environmental quality by promoting carbon sequestration and checking the losses of nutrients to water bodies and atmosphere. Besides, organic sources of nutrient acts as slow release fertilizer as it synchronizes the nutrient demand set by plants, both in time and space, with supply of the nutrients from the labile soil and applied nutrient pools.

Application of N, half as urea and half as farmyard manure, resulted in higher fertilizer N recovery by Pusa Basmati-1 rice, higher retention of fertilizer in soil and lower unaccounted for fertilizer N than sole urea application in a sandy loam soil. Green manuring crops grown in-situ (e.g. clover, vetch, cowpea, sesbania etc.) or brought from outside (e.g. Gliricidia) can be incorporated in soil to improve the crop productivity. For example 50-60 days old Sesbania aculeate, on an average, accumulates 4 to 5 t/ha dry matter or 100 to 130 kg/ha/N. The major constraint of green manuring is fitting it to the crop rotation and managing the extra inputs i.e. fertilizer and water by the poor farmers. When the crops are harvested mechanically a sizable quantity of crop residues are left in field that can be recycled for nutrient supply. Out of the nutrient taken up by cereals, on an average, 25 per cent of each N and P, 50 per cent of S and 75 per cent K are retained in crop residues making them available sources of nutrients. The low decomposition rate because of high C:N ration and immobilization of nutrients by cereal residues are some of the constraints in using them as source of nutrients. The major problem in using crop residues lies with the demand of these materials for other competing purposes e.g. animal feed and thatching of root etc. The NUE is considered altered when N fertilizers are applied in combination with organic manures, green manures, crop residues and biofertilizers (Sharma and Mitra 1990).

Bio fertilizer help in improving soil fertility through biological nitrogen-fixation, solubilizing P from native soil and applied sources and mobilizing the micronutrients like Zn<sup>++</sup> and Cu<sup>++</sup> for plant-uptake. Rhizobium strains play a major role in symbiotic N-fixation in legumes. Similarly blue-green algae, Azotobacter sp. and Azospirillum sp. Help in N-fixation in cereals. The vesicular-arbuscular mycorrhizal (VAM) fungi have an extensive mycelial network that increase the transport and uptake of P and micronutrients like Zn<sup>++</sup> and Cu<sup>+</sup> phosphate solubilizing microbes e.g. *Pseudomonas striata*, *Bacillus polymyxa* and *Aspergillus awamori* help in solubilizing of native soil P and rock phosphates.

Despite all the positive aspects of biofertilizers their use efficiency is highly soil, crop, location and management specific. It requires reliable system of storage, transportation and management in field to increase its acceptability among farmers. Legumes are known to increase soil fertility through their capacity to fix atmospheres N and hence the soil fertility can be improved by inclusion of a legume in the cropping system. Yields of cereals following legumes are reported to be 0.3 to 3 mg/ha; or 30-35 per cent higher than those following a cereal in cropping sequence. Besides N-fixation, legumes also help in solubilizing of occluded P, soil conservation, increase in soil microbial activity, organic matter restoration and improvement of physical health of soil.

### **Optimal allocation of nutrients**

The available nutrients should be optimally allocated among the competing crops to get the maximum returns by following optimizing of nutrient production functions which relate crop responses to applied nutrients under given soil, climate and management factors. Fertilizer allocation to crops based on soil test crop correlation approach for targeted yield can help in improving the nutrient use efficient by crops.

### **Enhancing recovery of added nutrients by crops**

The nutrient management practices that help in enhancing nutrient recovery by crops, maximizing yield and minimizing losses of nutrient lead to enhanced nutrient use efficiency. Some of these practices include selection of crops and cropping systems, balanced nutrition application and selection of proper, rate, time and method of nutrient application, optimum interaction with other inputs and amelioration of problem soils.

### **Balanced fertilization**

Major factor responsible for the low and declining crop response to fertilizers is the continuous mining of soil without adequate replenishment to a desired extent (NAAS, 35). The continuous use of N fertilizers alone or with inadequate P and K application has led to mining of native soil P and K. It is estimated that about 28 million tons of NPK are removed annually by crops in India, while only 18 million tons or even less are added as fertilizer, leaving a net negative balance of 10 million tones. Further, soil are getting continuously depleted of S and micronutrients like Zn, B, Fe and Mn due to continued adoption of intensive cropping systems and use of high analysis fertilizers without adequate addition of organics. Balanced fertilizer use at the macro level in India is generally equated with a nutrient consumption ration of 4:2:1 (N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O). The N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O ratio is as wide as 30.8:8.8:1 in Punjab, 48.2:14.9:1 in Haryana and 53.0:19.3:1 in Rajasthan compared with all India average of 6.9:2.6:1 (FAI.2004-05).

Balanced fertilizer i.e., use of fertilizer nutrients in right proportion and in adequate amount are considered as promising agro techniques to sustain yield, increase fertilizer use efficiency and to restore soil health (Yadav et al. 1998). Continuous heavy application of only one nutrient disturbs the nutrient balance and leads to depletion of other nutrients as well as to under-utilization of fertilizer N. The response of a crop to N not only depends on the status of N but also on the deficiency or sufficiency of other associated plant nutrients (Yadav et al.,

1998). Thus, balanced use of all nutrients is essential because no agronomic manipulation can produce high efficiency out of an unbalanced nutrient use.

### **Organic manure**

Organic manures are important to enhance use efficiency of fertilizer inputs and also serve as alternative source of nutrients to chemical fertilizers. Combined use of organic manure and N fertilizer maintains a continuous N supply, checks losses and thus helps in more efficient utilization of applied fertilizers. Incorporation and decomposition of organic manures has a solubilising effect on native soil N and other nutrients including micronutrients. Further, such integrated plant nutrient supply (IPNS) systems also help in mitigating the adverse effects of acidity due to chelation of excess Al<sup>+++</sup> and/or Fe<sup>++</sup> by the organic molecules liberated from FYM in the course of mineralization. The effect of FYM was found to be similar to like amendment in these acid soils, which seems mainly due to the formation of Al-organo chelates or complexes, resulting in the reduction of Al<sup>+++</sup> ion concentration in soil solution to levels beneficial to plant growth. In another study, apparent N recovery was increased when N fertilizer was applied along with organic manures such as biological study, FYM and Eupatorium adenophorum (Mahajan et al. 2002).

### **Application of green manuring**

Inclusion of legumes in cropping systems for green manuring, fodder or grain purposes is an assured agro-technology to improve nutrient-use efficiency, especially that of N. The advantages of green manuring are indicated by increased N availability in soil, higher recovery of green manure N and its greater contribution towards grain production of crop.

### **Selection of source, rate, and time and method of nutrient application**

The nature of fertilizer used and the rate, time and method of its application influences the recovery of the added nutrient by crop plants and it varies with the crop and root type. Ammonium nitrate is considered to be a better source of nitrogenous fertilizer for upland crops whereas ammonical and amide form of N are superior to the nitrate containing sources for lowland rice crop. However, urea is the most economic source of nitrogenous fertilizer. Fertilizer rates greater than the optimum level lead to lower utilization efficiency. Timing of fertilizer application should match with the crop demand. Split application of N is superior to basal application. P is usually applied as basal and in some light textured soils split application of K is advisable.

Method of applying fertilizers greatly affects their agronomic efficiency by influencing nutrient losses and their availability to plant roots. Superiority fertilizer application before pre-sowing irrigation over application of the same at the time of seeding for enhancing fertilizer use efficiency was reported by many workers. Similarly in rice, basal application of urea with no standing water is superior to broadcast application of urea into standing floodwater at 10 days after transplanting in reducing the volatilization losses of ammonia. The efficiency of water-soluble phosphatic fertilizers can be improved by band placement with, below or to the side of the seed row. This can improve the physical fertility of soil as the plants roots can easily take up nutrients from these sources. Many soils have large reserves of total phosphorus, but low levels of available phosphorus. Total P is often 100 times higher than the fraction of soil P available to crop plants. Most cereal growing areas in the developed world will overcome the problem of low P availability through management practices such as the application of phosphorus-based fertilizer/manure (Ortiz- Monasterio et al., 2002). P availability is strongly influenced by soil pH. Availability of P is maximized when soil pH is between 5.5 and 7.5. Acid soil conditions (pH < 5.5) cause dissolution of aluminum and iron minerals which precipitates with solution P effectively "tying" it up. Basic soil conditions (pH > 7.5) cause excessive calcium to be present in soil solution which can precipitate with P decreasing P availability. Land configuration and soil tillage have tremendous potential for its further exploitation and improving TFP. Yield enhancement is also possible by sowing crops in more innovative spatial patterns, such as in clumps rather than in rows (Bandaru et al., 2006).

### **Crop rotation involving legumes**

There is need to develop crop rotations involving legumes to tap the benefits of biological nitrogen fixation (BNF). Nitrogen use efficiency for cereals following legumes is greater than that for cereals following cereals or fallow. The role of legumes in N economy is well researched but the problem is how to increase N input and the options are increased system efficiency or increase in the area under the system. N derived from BNF in legumes varies from

40-80 per cent and residual effect on succeeding crops is variable and depends on several factors. The more intensive systems (growing more crops in a given period of time) require greater fertilizer N inputs but are economically advantageous to farming community. More intensive dry land cropping systems involving legumes in rotation lead to increased water use efficiency and also better maintain soil quality. The research has shown a positive impact of BNF on nitrogen economy of cropping systems but the vast potential of BNF has remained unrealized at the farmers' level due to many reasons and needs to be looked into from the holistic approach on nitrogen use in agricultural production systems.

There is an urgent need to improve the inputs of organics and Biological Nitrogen Fixation and to increase the production of quality inoculants and popularize their use in Indian agriculture rapidly. Development of effective and competitive strains tolerant to

high temperature, drought, acidity and other abiotic stresses are of high priority. Newer formulations of mixed biofertilizers, improvement of inoculant quality and devising effective delivery systems are crucial for making further progress in taking the BNF technology to farmers' fields.

### **Breeding input efficient crop varieties**

Breeding and selecting crop cultivars that make more efficient use of water and fertilizer N (including higher N fixation and N partition) while maintaining productivity and crop quality has been a long-term goal of production agriculture. Development of nitrogen-efficient cultivars could help decrease fertilizer N inputs and resulting reactive N losses to air and ground water. These nitrogen-efficient cultivars could also be useful in regions where limited-resource farmers are unable to afford synthetic N fertilizers. Selection of N efficient genotypes that is the varieties which can extract more N from soil at lower availability will enhance the production in these regions. Molecular and biotechnological approaches for searching for regulatory targets for manipulation of N use efficiency are strengthened.

### **Collaboration and accurate measurement**

Improving N-use efficiency in major food crops will require collaboration among ecologists, agronomists, soil scientists, agricultural economists, and politicians. Great needs exist for accurate measurements of actual fertilizer N-use efficiency, N losses, and loss pathways in major cropping systems. Only in this way we can: a) identify opportunities for increased N-use efficiency by improved crop and soil management; b) quantify N-loss pathways in major food crops; and c) improve human understanding of local, regional, and global N balances and N losses from major cropping systems. The starting point for any improvement has to be a clear understanding of the fluxes and balances of nitrogen at the farm level. Direct on-farm measurements are necessary because estimates from small plots on research stations overestimate field-scale fertilizer N-use efficiency (NAAS 2005).

### **TECHNOLOGIES FOR INCREASING PHOSPHORUS (P) USE EFFICIENCY**

For Phosphorus (P) management, nutrient omission technology that deter-mines the soil supplying capacity and crop requirement for P in individual fields is suggested (Dobermann and Fairhurst, 2000). It is estimated that only 20-25% of the applied P is used by cereal crops and the rest is retained in the soil as residual P. In general, high water solubility of P will be required for alkaline and calcareous soils and for wheat more than for rice. P-use efficiency in the case of its placement below the soil surface and into the root zone of wheat was 1.5 times higher than when it was broadcast (Vig and Singh, 1983). Balanced fertilization is the key to increasing the use efficiency of plant nutrients as it ensures the application of fertilizers in adequate amounts and correct ratios for optimum plant growth. Efficient nutrient management holds the key in RW double- or triple-cropping systems in which there is hardly any scope for keeping fields fallow between two crops. Also, nutrient recycling through organic manures is important, as shown for highly intensive triple-cropped rice-wheat-corn or rice-wheat-mung bean systems in Bangladesh (Panaullah et al., 2006; Saleque et al., 2006; Timsina et al., 2006). Whenever feasible, inorganic fertilizers should be used in conjunction with organic manures.

### **TECHNOLOGIES FOR INCREASING POTASSIUM (K) USE EFFICIENCY**

K-fertilizers are generally broadcast or spread on the surface and mixed with the soil at sowing. At low level of available K or with a high K-fixing capacity. Band placement is recommended for enhancing fertilizer use efficiency. Split application is emerging as an alternative to basal application. Split application is advocated in Rice grown in light textured soils and acid soils in high rainfall areas in

order to reduce leaching losses. Under low tillering and late maturing varieties where natural supply of K from soil plus irrigation water decreases in the later stages of crop growth.

### CONCLUSION

As one of the world's largest agricultural production systems spread over 26 Mha in the IGP of South Asia and China, the RW cropping system meets the staple food requirements of more than one billion people. In the three decades between 1970 and the end of the twentieth century, the annual increase in rice production in the IGP was 4.1%, much greater than that achieved over the entire Indian rice belt (2.1%) over the same period. The annual rate of increase in wheat production during the same period was 4.4% in the IGP compared with 3.4% for the entire country. This increase in wheat and rice production in the IGP resulted from the introduction of input-responsive high-yielding crop varieties along with matching production and protection technologies, infrastructure development, and a protective minimum support price policy (assured purchase by the government).

With recent legislation in the form of the National Food Security Bill, the government of India aimed to provide access to food for all at an affordable price and a buffer stock of 62

M tons will have to be maintained in the country. With increasing pressure on natural resources, particularly land and water, decreasing labour availability, changing economic and social obligations, impact on environment of the current farming practices, increasing mechanization,

etc., the RW system is under pressure to fulfil the increasing food needs of the rising population of more than nine billion people forecast by 2050. There is little scope for further expansion of area under RW, an increase in cropping intensity, and reclamation of degraded soils. The productivity gains of the past have, in fact, slowed down and there is an urgent need for a technological breakthrough to halt this downward trend and sustain productivity in the region.

Nutrient management in proper way not only sustained the productivity over a long period but also improve soil properties, incorporation of residual biomass in large quantities as result of better harvest on balanced application nutrient is responsible of sustaining the crop productivity and soil health. External supply of nutrient in balanced from also improved the physical condition and biological activity in soil which favours nutrient transformation in soil. Thus nutrient management is only option to sustain the productivity and improving the soil health.

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