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Increasing Agricultural Productivity through Site-Specific Nutrient Management

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Introduction

Green Revolution technologies have allowed the food supply of Asia to satisfy the demand of its rapidly growing population in the past decades; however, the pressure on soil and other resources has intensified. The cultivated area is continuously decreasing because of soil pollution, land abandonment, urbanization, and other reasons. Meanwhile, the population and the demand for food continue to increase. Under such a situation, increasing cropping intensity from monoculture to double or triple cropping in a year is an efficient way to guarantee food security on the amount of agricultural land now available.

Over the past four decades crop management in India has been driven by increasing use of external inputs. Fertilizer nutrients have played a major role in improving crop productivity and production. During the period 1969-2010 food grain production more than doubled from about 98 M tons to 212 M tons in 2001-02,while fertilizer nutrient use increased by >12 times from 1.95 M tons to more than 23 M tons in 2007-08. Notwithstanding these impressive developments, food grain demand is estimated to increase to > 300 M tons per annum by 2025 for which the country would require about 45 M tons of fertilizer nutrients (ICAR, 2008). With no scope for further increase in net cultivated area (~142 M ha), much of the desired increase in food grain production has to be attained through productivity enhancement of major crops like rice, wheat, maize (contribute > 80% to total food production) by 3.0 to 7.5% annually (NAAS, 2006). Increasing genetic potential of genotypes, and more importantly improving use efficiency of resources and inputs like water, nutrients etc. through their efficient management involving conjunctive use of organic and inorganic sources and based on crop demand and location specificity are essential to economize input costs and improve factor productivity. The issue becomes more complex with increasing cropping intensity and cultivation of high yield potential cultures in view of the observed discouraging impacts of green revolution technologies on soil resource quality and its productivity. Nutrient management is a major component of a soil and crop management system. Knowing the required nutrients for all stages of growth and understanding the soil's ability to supply those needed nutrients is critical to profitable crop production.

The growing concern about impaired soil health, declining/decelerating productivity growth and decreasing factor productivity or efficiency of the nutrients compelling to use increasing levels of fertilizers during the last two decades has raised apprehensions on the productive capacity of the agricultural system. The response to fertilizers use has decreased from 17 kg grain kg^{-1} nutrient in 1951 to 5-6 kg grains now, which ideally should be in the range of 18-25 kg grain kg^{-1} nutrient. Data from farmers' fields (1999 – 2003) showed cereals responding around 8-10 kg grain kg^{-1} fertilizer (average). Traditional practices of organic manuring and growing of soil fertility restoring crops have gradually declined while nutrient outflows through crop production indicated an apparent negative balance of nearly 10 million tons at the national level, which is likely to increase to 16 million tons by 2012. The recovery efficiency of fertilizer nutrients is about 20-40, 15-20 and 40 -50% for N, P and K, respectively while for secondary and micronutrients it is substantially low ranging 5-12%. Major factors contributing to the low and declining crop responses to fertilizer nutrients are continuous nutrient mining from the soil due to imbalanced nutrient use (7:2.8:1 NPK) leading to depletion of some of the major, secondary and micro nutrients like N, K, S, Zn, Mn, Fe, B etc., decreasing use of organic nutrient sources such as FYM, compost and integration of green manures/grain legumes in the cropping systems and mismanagement of irrigation systems leading to serious soil degradation qualitatively. Such decline in soil fertility status (due to negative balance of nutrients) is likely to end with irreversible damage to the nutrient supply system if followed further and could impact production costs with serious environmental consequences.

Recent research conducted in many Asian countries, including Northwest India (Ladha *et al.*, 2003; Pathak *et al.*, 2003), has demonstrated limitations of the current approach of fixed-rate, fixed-time (blanket) fertilizer recommendations being made for large areas. This is mainly because this approach does not take into account the existence of large variability in soil nutrient supply and site-specific crop response to nutrients among farms (Timsina and

Connor, 2001). Indeed, factors affecting crop yield and quality are site-specific (Reets and Fixen, 2000). This helps to explain why fertilizer N use efficiency is usually poor, the use of P and K fertilizers is often not balance with crop requirements and other nutrients and, as a result, profitability is not optimised (Dobermann *et al.*, 1998; Olk *et al.*, 1999).

Therefore, to ensure that nitrogen and other essential plant nutrients are provided in optimal amounts, and are readily available during crop-growth periods, site- specific nutrient management (SSNM) was developed in Asia by the International Rice Research Institute (IRRI). SSNM is a low-tech, plant need-based approach for optimally applying nitrogen, phosphorus, and potassium fertilizers to crops as and when they are needed (IRRI 2006). As aresult, wider farmer adoption of SSNM will increase land productivity, yield, and profitability of farmers, and decrease fertilizer-related pollution in the environment.

Site-Specific Nutrient Management

Concept:

Site-specific nutrient management (SSNM) is a widely used term in all parts of the world, generally with reference to addressing nutrient differences which exist within fields, and making adjustments in nutrient application to match these location or soil differences. Site specific management includes practices that have been previously associated with maximum economic yield management, best management practices as well as general agronomic principles. The earliest use of the term ‘site-specific’ comes from the late 1920’s in USA, when scientists at the University of Illinois were providing recommendations on the application of lime to acidic soils (Jones 1993). In the mid to late 1980’s, the development of GIS and GPS technology, and the associated use of this in agriculture to map variability, fostered the use of ‘site-specific management’ approaches in the developed world (Harold Reetz). Simultaneously in India, the International Plant Nutrition Institute (IPNI) started a site specific soil testing and assessment programme, which can best be described as a ‘systematic approach to soil fertility evaluation’.

The SSNM provides an approach for need based feeding of crops with nutrients while recognizing the inherent spatial variability. It involves monitoring of all pathways of plant nutrient flows/supply, and calls for judicious combination of fertilizers, bio fertilizers, organic manures, crop residues and nutrient efficient genotypes to sustain agricultural productivity. It avoids indiscriminate use of fertilizers and enables the farmer to dynamically

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adjust the fertilizer use to fill the deficit optimally between nutrient needs of the variety and nutrient supply from natural resources, organic sources, irrigation water etc. It aims at nutrient supply at optimal rates and times to achieve high yield and efficiency of nutrient use by the crop. SSNM approach involves three steps – establishing attainable yield targets, effectively use existing nutrient sources and application of fertilizers to fill the deficit between demand and supply of nutrients.

Soil nutrient supply potential and its spatial variability, productivity potential and targets for crops and cropping systems, estimation of nutrient requirements, and fertilizer use efficiency besides assessment of resource quality and socioeconomic background of the farmers are essential for developing site specific IPNS.

Principle and Advantages Of Adopting Ssnm:

Site Specific Nutrient Management (SSNM) is an approach to feeding crops with nutrients as and when needed. The application and management of nutrients are dynamically adjusted to crop needs of the location and season.

1: Balanced fertilization based on crop requirements

The SSNM offer a basic plan for a preseason calculation of balanced fertilizer rates considering the deficit between plant nutrient requirement and soil nutrient supply. This deficit largely depends on the expected yield gain, which we define as the required yield increase over the nutrient-limited yield to reach a season-specific yield goal. To consider differences in indigenous supply among nutrients, yield gains have to be estimated for N, P, and K separately.

2: Plant-based estimation of soil nutrient supplies

The opportunities to improve current fertilizer recommendations through the use of conventional soil tests are limited. Soil properties and rapid chemical extractions of soil samples showed few correlations with indigenous N, P, and K supply measured as plant nutrient uptake in nutrient omission plots across a wide range of on-farm environments (Dobermann *et al.*, 2003). An alternative to soil testing, soil nutrient supply can be indirectly estimated by plant nutrient uptake in nutrient omission plots. Plant-based estimates of soil nutrient supply integrate the supply of all indigenous sources estimated under field conditions and also offer the possibility for estimating the nutrient-supplying power of organic manures, irrigation, and biological N_2 fixation (Dobermann *et al.*, 2003).

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3: Need-based fertilizer N management

Farmers generally apply fertilizer N in several split applications, but the number of splits, amount of N applied per split, and the time of application vary substantially. The apparent flexibility of farmers in adjusting the time and amounts of fertilizer application offers potential to synchronize N application with the real-time demand of the crop. Three main forms of N management recommendations can be briefly summarize: (1) location-specific split schedules for preventive N management, (2) corrective N management using a leaf colour chart (LCC),and (3) a combination of both in which the LCC is used at certain growth stages to identify the need for fertilizer N (split N + LCC).

a). Location-specific split schedules for preventive N management involve preset fertilizer N applications at key growth stages of crop. General recommendations for N application regimes are widespread, and were often developed through N fertilizer response experiments. Location-specific split schedules can be developed where fertilizer N requirements are calculated on the basis of crop requirements and soil indigenous N supply. An estimate of the latter can be obtained by analyzing current farm yields and farmers' N management strategies in combination with local knowledge on soil fertility. Locally refined splitting patterns have to take into account specific needs for differences in climatic seasons, varieties, crop establishment, basal N application, and water management(Witt *et al.*, 2002, Dobermann and Fairhurst, 2000).

b). LCC-based corrective N management is a true real-time N management approach, in which the plant N status is periodically assessed and application of fertilizer N is delayed until (almost when) N-deficiency symptoms appear. This "need based N management" does not require the estimation of soil N supply or the calculation of a preseason fertilizer rate. Leaf colour is a visual and subjective indicator of plant N deficiency, and the LCC with its six colour panels of different shades of green is used as a reference tool. Need-based N management requires the identification of an optimal leaf colour that needs to be maintained throughout the season to obtain high yields. The optimal leaf colour (or critical LCC value) varies depending on cultivar and crop establishment method. Guidelines for the use of the LCC include reading of leaf colour at 7–10 days intervals from early tillering until flowering. When the average leaf colour falls below the critical value, a predetermined rate of N fertilizer is applied immediately to prevent N deficiency.

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c). Location-specific split schedules, including the LCC, combine preventive and corrective N management strategies. Total fertilizer N requirements are calculated as described for location-specific split schedules, including guidelines for the need of basal N application. At advanced growth stages, the LCC is then used to adjust predetermined N doses upward or downward depending on the plant requirement for fertilizer N (Witt et al 2002a). This dual strategy is similar to the SPADmeter approach described by Dobermann *et al.* Using the LCC in combination with application schedules may address farmers' preferences and needs at certain sites to reduce reliance on frequent visits to the field. This strategy also reduces the risk of temporal N deficiency caused by the inaccurate use of the pure LCC approach.

4. Sustainable P and K management

The estimation of P and K requirements is challenging for individual farmers because of small landholdings and substantial variation in soil P and K supplies within small domains (Dobermann *et al.*, 2003). Information on soil nutrient supply is of particular importance for the commonly less limiting macronutrients P and K because of (1) uncertainties in short- and long-term crop responses to P and K application and (2) limited options to correct for deficiencies of these nutrients within a season as compared to N. In general, P and most K should be applied early in the season for greatest efficiency and to avoid nutrient deficiencies at early growth stages. This requires a conceptual framework to assist farmers in the estimation of total fertilizer P and K requirements to maintain indigenous P and K supplies or increase them when necessary.

The refined SSNM approach to develop simple charts with fertilizer P and K rates were based on a broad classification of yield goals, indigenous nutrient supplies, and nutrient inputs with crop residues. The fertilizer P requirements largely depend on the deficit between yield goal and soil nutrient supply, and the suggested maintenance fertilizer P rates for conditions where a direct crop response is not expected would increase slightly with an increase in the targeted yield level. Substantial amounts of fertilizer K would be needed, especially at elevated yield levels, to balance K removal.

5. Increasing profitability

The major benefit for farmers from improved nutrient management strategies can be expected from an increase in the profitability of cropping. SSNM principles can accommodate a wide range of socioeconomic conditions, including situations of labour shortage. Small amounts of additional labour may be required, but labour costs for nutrient management are relatively small compared with those for land preparation, transplanting, or harvesting. Efficient N management may also result in off-farm environmental benefits through a reduction in fertilizer N use without sacrificing yield, especially in situations in which N input is very high. This may increase the profitability to some extent, especially in cases of very high fertilizer N inputs. Large reductions in N use in such locations may also increase farm profits. The major potential for increasing farm profitability through innovative nutrient management therefore lies in increasing yield through efficient N management and balanced nutrition, unless a reduction in other inputs such as pesticides offers substantial additional savings.

Future Challenges and Extension:

Major challenges for SSNM research in future will be two-fold: To retain the demonstrated potential of the approach, and upon what has been already achieved using while reducing the complexity of the technology as it is disseminated to farmers and their advisors. Thus, there is a need to further refine location-specific N management strategies and test them against other forms of N management. The nature of the SSNM approach will need to be tailored to specific circumstances in different situations. In some areas, SSNM may be site- or farm-specific, but in many areas, it is likely to be just region- and/or season-specific. Thus, a simplified future SSNM approach should combine decisions that are made on a site-specific as well as decisions that are valid for somewhat larger regions with similar agro-climatic conditions. Estimates that allow placing a site into one of several broad categories of indigenous nutrient supply (as is being done for the rice crop already [IRRI 2006]) are probably sufficient for most SSNM applications and are easier to follow. Existing, recently developed soil maps can then be used to delineate and verify such recommendation domains with similar soil indigenous nutrient supplies. While improved blanket recommendations for reasonably large areas will probably be sufficiently robust for P and K, the algorithm used for applying fertilizer N needs simplification, including the replacement of the SPAD meter with the cheaper leaf colour chart.

For extension of SSNM, the development of decision support system (DSS) programmes like the Nutrient Manager is a good example of the type of technology industry and extension agronomists can use to support nutrient management decisions at the field level in villages. Developing Nutrient Manager for wheat and maize are logical goals considering the high acreage under these crops and their importance for food and nutritional security in the country. A stronger emphasis will have to be given to farmer participatory approaches to identify the N management strategy most acceptable to farmers prior to wider-scale dissemination. Extension workers will need to be trained so that they can share their newly acquired knowledge with farmers. The new strategy could then be promoted through farmers' group meetings, monthly zonal meetings of extension personnel, and mass media such as newspapers and radio. Regional and state support will be required to implement SSNM on a larger scale, including funding for promotional material and the manufacture and distribution of LCCs. In view of current water and labour shortages at the time of transplanting, some farmers will likely change from transplanting to direct seeding in the near future. Crop establishment technologies that are currently under investigation include broadcasting of dry or pre-germinated rice seeds and a newly developed drum seeder. SSNM technology will need to be adjusted if farmers change their crop management practices.

Conclusion:

Site-Specific nutrient management (SSNM) is an approach mapping the variation with in the field for feeding crops with nutrients as and when needed. Site-Specific nutrient management aims at increasing farmers' economy return and reducing negative impact on environment. SSNM is an integrated practice such as maximum economy yield management, best management practices, as well as general agronomic principles. Site-specific nutrient management must become an integral component of a wider, integrated crop management approach. Major differences among soil type, water management, and pest control appear to be of greatest importance for improving crop response to nutrients. The SSNM strategy also requires further simplification to make it fit for wider scale delivery to farmers.

Site-Specific nutrient management will be the key to nutritional security of the country in the coming years.

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