Nutrient Management Research Priorities in Rice-Maize Systems of South Asia

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Rice-maize (R-M) systems are emerging all around South Asia, but in particular they are developing rapidly in Bangladesh and South and North India. Nutrient demand of R-M systems can be high due to the nutrient extraction of high-yielding crops. Nutrient balance studies for these highly productive and nutrient extractive systems are scarce in South Asia. Developing, refining, and disseminating the integrated plant nutrition system based on site-specific nutrient management (SSNM) principles have been identified as priorities for future research to further increase yield, profitability, and sustainability of R-M systems.

Maize is rapidly emerging as a favorable option for farmers in South Asia as a component crop of rice-based systems. Drivers of such changes are higher productivity and profitability of maize over winter rice or wheat, the two competing cereal crops grown in the winter season in South Asia (Ali et al., 2008, 2009). Far less water is required for maize, as compared to winter rice and wheat. This is viewed as a promising mitigation option of the arsenic (As) problem in the Gangetic regions of West Bengal and Bangladesh where uptake of As with water and its subsequent movement through the food chain (soil-plant-animal continuum) is a great concern. Maize is also considered to be a better alternative to counter abiotic stresses such as terminal heat stress in wheat in eastern India and Bangladesh, and water scarcity in peninsular India. Maize has fewer pest and disease problems than winter rice or wheat. A combination of the above reasons, along with the suitability of maize in the three major cropping seasons of South Asia (Timsina et al., 2010), support diversification from the existing cropping systems to rice-maize systems.

High yielding R-M systems extract large amounts of mineral nutrients from the soil. Proper nutrient management of exhaustive systems like R-M should aim to supply fertilisers adequate for the demand of the component crops, and apply those in ways that minimise loss and maximise the efficiency of use. Of all the nutrients, N, P, and K remain the major ones for increased and sustained productivity. However, high yielding R-M systems can also accelerate the problem of secondary and micronutrient deficiencies, not only because larger amounts are removed, but also because the application of high rates of N, P, and K to achieve yield targets often stimulates the deficiency of secondary and micronutrients (Johnston et al., 2009).

Nitrogen management in the R-M system will require special attention so that potentially large losses can be minimised and efficiency can be maximised. During the growing season of rice, the aim of fertiliser management should be to reduce N loss through denitrification, volatilization, and leaching by either deep placement or split applications to match crop demand and to increase N-use efficiency. The return to aerobic conditions at the end of the rice season sees rapid nitrification of newly formed and existing ammonium. Once the following maize crop is established, split applications of N fertiliser can supplement mineralisation of soil organic matter to meet the N requirement of the crop without undue loss, even under irrigation. Water availability during the dry winter period varies among R-M agro-ecosystems and will determine yield of the maize crop and hence its N requirement. Higher N use efficiency of the system can be achieved if the maize crop leaves little mineral N at the end of the season because high residual soil N may either depress N fixation by a legume crop such as mungbean, or will be lost during puddling for rice (Buresh and de Datta, 1991).

Abbreviations: N = nitrogen; P = phosphorus; K = potassium.

Rice and maize are grown on 3.5 million hectares (M ha) in Asia, of which 1.5 M ha are in South Asia.

Phosphorus tends to accumulate in the soil due to fixation by iron (Fe) and aluminum (Al), especially in acidic soils. Over time, large amounts of P can be fixed in that way (Kirk et al., 1990) while slowly contributing to the available P pool of the soil. Phosphorus, however, solubilises immediately after flooding, leading to a flush of available P (Kirk et al., 1990) increasing its supply to rice. Subsequent drying, however, reduces its availability to maize for which strong crop responses to P fertiliser are expected (Sah and Mikkelsen, 1989). In systems of low P fertility, the repeated dry-wet transition in the R-M system increases P extraction, further lowering fertility.

The increased concentrations of ferrous iron (Fe^{2+}), manganese (Mn), and ammonium (NH_4^+) in flooded soils during rice cultivation displace K from the exchange complex into the soil solution. This displacement, however, ceases on return to aerobic conditions. Despite often having relatively high total K content, the K nutrition of R-M systems grown on the soils of South Asia is not always assured. This is attributed to many heavy-textured alluvial floodplain Terai soils of Nepal and northern and eastern India, and the soils of Bangladesh that contain K-fixing minerals (Dobermann et al. 1996, 1998). It may seem appropriate to make differential applications of K to component crops in R-M systems on non-K fixing soils with the aim of preventing loss by leaching. Finally, K inputs from irrigation or rainwater need to be considered (Dobermann et al. 1998) along with K inputs from sediments deposited from flood water while formulating a rational K management strategy for R-M systems. Application of a full maintenance rate of K (input=output) may not be profitable for rice and maize under situations where crop response to K is poor. In such scenarios, some K mining may be allowed by applying K below maintenance rate (Buresh et al., 2010) based on better understanding of how much mining can be allowed in a particular soil without compromising fertility levels.

Site-Specific Nutrient Management in R-M Systems

In south Asia, existing fertiliser recommendations for rice and maize often consist of one predetermined rate of nutrients for vast areas of production. However, the growth and needs for supplemental nutrients of any crop can vary greatly among fields, seasons, and years as a result of differences in crop-growing conditions, crop and soil management, and climate. SSNM for rice and maize enables adjustments in nutrient application to accommodate the field-specific needs of the crop for supplemental nutrients.

Emerging evidence from SSNM experiments in South Asia are highlighting the applicability and necessity of SSNM in R-M systems. SSNM experiments on R-M systems located in Hyderabad, India, revealed that highest yields for both rice and maize, and highest system productivity were obtained from the SSNM treatment (Timsina et al., 2010). Omission of N from the optimum treatment reduced yield by about 1 t/ha and 3 t/ha in rice and maize, respectively. Yield loss in rice and maize (0.8 t/ha and 1.5 t/ha, respectively) was similar in P and K omission treatments. This suggests that N is by far the most limiting nutrient and greater response to applied nutrients is expected in maize than rice, possibly due to a combined effect of higher yield potential in maize and the change from puddled submergence conditions in rice to a more aerobic ecology in maize. Data from another set of multiple location SSNM experiments in two major maize-based cropping systems, i.e. maize-wheat and rice-maize in India (Timsina et al., 2010) showed significant yield improvement of maize under SSNM compared to general recommendations. Omission plot yield data revealed differential indigenous nutrient supplying capacity of the study sites across locations (agro-ecologies) and the authors suggested that response to applied nutrients as well as off-take of nutrients over a cropping season must be included as criteria to develop recommendations under no or limited response scenarios.

In two districts of northwest Bangladesh, grain yield data from on-farm SSNM trials with rabi maize show large yield

Effects of omission of P and K are shown in these photos from maize plots.

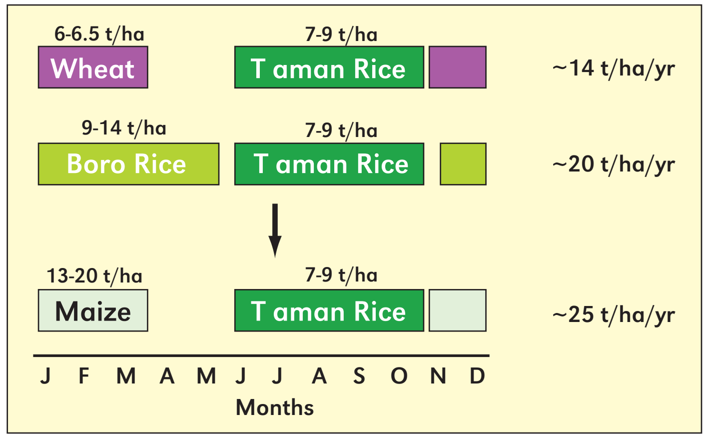

Figure 1. Potential grain production of rice-based cropping systems in Dinajpur, Bangladesh.
Source: Pasuquin et al. 2007

responses to N addition **(Table 1)** (Timsina et al., 2010). Yields in the nutrient omission treatments varied widely across farmer fields within a district and also differed in the two districts, indicating large variations in the indigenous nutrient supplying capacities of the soils. Yields in the minus N treatment were low. However, in low P and low K treatments they were quite close to the sufficient yields achieved in the NPK treatment indicating large response to added N, but low response to added P and K due to variation in indigenous soil nutrient supply.

Table 1. Grain yield (t/ha) of winter maize from on-farm SSNM experiments in Bangladesh.

Treatments	Rangpur	Rajshahi
N omission	0.5 to 5.1	3.4 to 3.9
P omission	3.9 to 8.3	4.5 to 8.5
K omission	4.1 to 8.1	5.3 to 7.9
Low K	5.5 to 8.8	6.2 to 8.9
Low P	5.8 to 9.8	6.5 to 8.6
NPK	6.0 to 10.3	6.7 to 10.3
NPKSZn	6.0 to 10.4	7.2 to 10.8

This high variability in response to applied N, P, and K across agro-ecologies suggests the necessity of SSNM to improve productivity of R-M systems as well as the component crops. Very high yield losses in maize due to N omission might be associated with the loss of SOM due to dry tillage in aerated soil after rice cultivation under submergence (Pampolino et al. 2010), and may need serious consideration for reduced or zero-till cultivation of maize with residue retained from the previous rice crop. Timsina et al. (2010) hypothesized that the establishment of maize after rice with reduced or no tillage, and retention of crop residues, could help conserve SOM and maintain soil fertility provided improved nutrient management is practiced. Experiments are underway in South Asia, particularly in India and Bangladesh, comparing maize and rice under conventional, reduced, and zero tillage in R-M systems to standardise nutrient management practices.

Estimating Fertiliser Needs for R-M Systems

Maize hybrids grown during the winter season in South Asia have an attainable grain yield of 10 to 12 t/ha, with similar non-grain biomass. Such biomass generation can often be associated with removal of 200 kg N, 30 kg P, 167 kg K, and 42 kg S per hectare (BARC, 2005). Studies in R-M systems in

Bangladesh have shown highly negative N and K balance (120 to 134 kg and 80 to 109 kg/ha, respectively) with positive P balance (Ali et al., 2008, 2009). So nutrient requirement of intensive R-M systems must be associated to attainable yield (Yat) levels of the component crops. Buresh and Timsina (2008), using crop simulation models for rice and maize, showed that attainable annual yields were markedly higher for R-M (17.3 t/ ha) than Rice-Rice (R-R) (14.1 t/ha) cropping systems, suggesting much higher nutrient extraction and fertiliser needs for R-M than R-R as these cropping systems approach their Yat. The Yat of maize estimated by the authors (11.1 t/ha) was markedly higher than the currently reported average farmers' yield of 8 t/ha, indicating opportunities for future increases in maize yield through improved crop and nutrient management practices. The estimated yield can subsequently be used to assess evolving fertiliser needs as cropping system diversify, intensify and increase in yield.

Likewise, Pasuquin et al. (2007) demonstrated how diversification from R-R or Rice-Wheat (R-W) systems to R-M systems can impact on nutrient use in Bangladesh. There is no alternative to growing summer rice (T. aman) in the rainy season so the production potential changes depending on the second crop grown. The production potential is highest for R-M systems with about 25 t grain/ha/yr, followed by R-R (20 t/ha/yr) and R-W systems (14 t/ha/yr) **(Figure 1)**. Because crop yield is directly related to the amount of nutrients taken up by a crop, fertiliser consumption is expected to increase when farmers shift from either a R-R or a R-W system to R-M systems due to a greater demand for nutrients at higher production levels. Shifting from one crop to another is likely to have moderate impact on fertiliser demand, while shifting from a single to a double, or from a double to a triple-cropping system, would result in increased fertiliser consumption and demand, as well as increased farmers' productivity.

Future Priorities for Research in Nutrient Management for R-M Systems

As maize cropping becomes more widespread and intensive in South Asia, and particularly in Bangladesh and South India, an emerging issue of great importance is how to sustain the productivity of R-M cropping systems through integrated soil fertility management strategies. Continuous production of high yielding maize will lead to the rapid depletion of mineral nutrients from soil because of the greater nutrient uptake and removal by maize than other cereals such as rice or wheat. SSNM strategies for rice and maize separately have now been well developed (Fairhurst et al., 2007; Witt et al., 2007). Future research and dissemination should now focus on developing SSNM principles for R-M systems considering the yield goals, crop demand, indigenous soil nutrient levels, and residual soil fertility. Decision support systems (DSS) based on developed principles at a later stage would help farmers and extension workers to adopt SSNM strategies for R-M systems. Such DSS, namely Nutrient Manager (Buresh et al., 2010) and Nutrient Expert (Witt et al., 2009), for cereals are in the development and evaluation stage in South Asia.

There is, however, a need to understand more about the extent and rate of nutrient depletion and soil physical degradation in the intensifying R-M systems in South Asia. To push the achieved grain yields even higher up the yield potential curve will require larger amounts of nutrients, their better management and overall soil stewardship. On-farm nutrient management experiments that optimise high-yielding rice/ maize crops are required to understand how management of such systems can meet the requirements of rice and maize in South Asia given the generally low fertility soil resource base.

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Dr. Timsina is shown visiting a maize field.

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