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# An evaluation of nutritional constraints on irrigated rice yield

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## Introduction

Asian rice farmers try to afford good management for irrigated rice for a good harvest, but hidden hunger of certain nutrients, other than nitrogen, often limit rice yields. By keeping P and K fertilizers away from the fertilizer inputs for intensive cropping systems, such as rice-wheat (RW) (Timsina and Connor, 2001), and with the inclusion of modern cultivars of wheat and rice, many soils of the IGP, including Bangladesh, have become P and K deficient (Ali et al., 1997). Recent soil tests show that many soils of the IGP, with available K concentration below 0.1 meq/100 g soil, are becoming deficient in K despite originally high contents. Mean annual balance of P was found – 1 to – 9 kg ha $^{-1}$ (Saleque et al, 2006) and that of K was as high as – 25 to – 212 kg ha $^{-1}$ (Panaullah et al, 2006) across different soils of Bangladesh. Application of P and K definitely increase rice yields in soils that became deficient in these elements. However, less conspicuous deficiency symptoms of P and K in rice compared to the symptoms of N and S restrain farmers from applying these fertilizers.

Plant tissue analysis is a good tool to identify nutrients deficiency in crop. There are several approaches to interpret plant nutrient composition – critical value (CVA) (Munson and Nelson 1990), diagnosis and recommendation integrated system (DRIS) (Walworth and Sumner 1987) and compositional nutrient diagnosis (CND) (Parent and Dafir 1992). Yoshida (1981) presented critical leaf nutrient content for rice. Bell and Kover (2000) developed DRIS norms for rice plant. The CND improved the yield – tissue N relationships as polynomial or linear–plateau curves compared with CVA in conifer seedlings, onion and potato (Parent et al. 1995). The CND approach is applicable to small-size crop nutrient database for solving nutrient imbalance problems in specific agroecosystems (Khiari et al. 2001a). The present investigation aimed (i) to select a minimum yield target for the high-yielding subpopulation from a small rice yield database and (ii) to determine the differences in nutrient composition of high and low–yielding subpopulation of rice grown in farmers' fields.

## Materials and Methods

Boro, dry season irrigated rice, was grown on 42 farmers' fields in piedmont soils, Bangladesh. Two nutrient-management plans were tested in three farmers' management zone (FMZs) of Bangladesh (Saleque et al. 2008). One of the plans was farmers' practice (FP), which was farmers' traditional nutrient-management program; another one was improved nutrient-management plan (INM), nutrient required for rice based on soil-test results for the specific management zone. The nutrient doses in FP varied from place to place and between FMZs within a site. For FP, doses of N, P and K varied from 32 – 135, 4 – 25 and 0 – 19 kg ha $^{-1}$, respectively. In case of INM, the doses of N, P and K varied from 70 – 170, 15 – 19 and 46 – 62 kg ha $^{-1}$, respectively.

At 45 - 50 days after transplanting (DAT), the most recent expanded leaf (third leaf from the top) was sampled from each plot to determine nutrient concentration. The leaf sample was oven dried at 69 °C for 72 h and ground by Wiley Mill. The ground sample was digested with concentrated $H_2SO_4$ and total N concentration was determined by micro Kjeldahl distillation (Yoshida et al., 1976). The concentration of P, K, Ca, Mg, Zn, Fe, and Mn was analyzed by digesting a 0.2 g leaf sample with 5 mL of 5:2 $HNO_3$:$HClO_4$ (Yoshida et al. 1976).

Leaf nutrients concentration and nutrient ratios were calculated. Compositional nutrient diagnosis (CND) row-centered log ratios for d + 1 nutrient proportions including d nutrients and a filling were determined according to Khiari et al. (2001a).

Row-centered log ratios were computed as follows:

$$V_X = \ln\left(\frac{X}{G}\right)$$

where $V_X$ is the CND row-centered log ratio expression for nutrient X and G is the geometric mean of the nutrients composition including the filling value. By definition, the sum of tissue components is 100%, and the sum of their row-centered log ratios including the filling value must be zero.

Cumulative variance ratio function of each $V_X$ was calculated after Khiari et al. (2001a) as follows:

$$F_i^C(V_X) = \frac{\sum_{i=1}^{n_1-1} f_i(V_X)}{\sum_{i=1}^{n-3} f_i(V_X)} \times 100$$

where $n_1 - 1$ is partition number and n is total number of observations ($n_1 + n_2$). The denominator is the sum of variance ratios across all iterations, and thus is a constant for component *X*.

The cumulative function $F_i^C(V_X)$ was regressed to yield (Y) in cubic model as follows:

$$F_i^C(V_X) = aY^3 + bY^2 + cY + d$$

Differentiating the equation with respect to Y twice gives,

$$\frac{\partial^2 F_i^c(V_X)}{\partial Y^2} = 6aY + 2b$$

The inflection point, yield cutoff value for high and low yield subpopulation, can be obtained when

$$6aY + 2b = 0$$

$$\text{or, } Y = -\frac{b}{3a}$$

The highest yield cutoff value across nutrient expressions (N, P, K and S) were selected to ascertain that the minimum yield target for a high-yield subpopulation.

Descriptive statistics were determined for leaf nutrient concentration and nutrient ratio expression data. Statistical parameters were evaluated using Excel software and included, means, variances, CV's and skewness values, where a skewness value of zero indicates perfect symmetry, and values greater than 1.0 indicate marked asymmetry. All computations were made using Excel software (Microsoft, 1997).

## Results

The cutoff yield between the low– and high–yielding subpopulations obtained from cumulative variance ratio functions of nitrogen, phosphorus, potassium and sulfur ranged from 3.26 to 6.90 Mg $ha^{-1}$ (Table 1). These nutrients are usually deficient in the study area and fertilizer application for these nutrients is recommended. The yields (Mg $ha^{-1}$) at inflection points of the cubic functions, computed by setting the second derivative of $F_i^C(V_X)$ to zero were 4.33 Mg $ha^{-1}$ for $F_i^C(V_N)$, 3.26 Mg $ha^{-1}$ for $F_i^C(V_P)$, 6.90 Mg $ha^{-1}$ for $F_i^C(V_K)$, and 3.98 Mg $ha^{-1}$ for $F_i^C(V_S)$, respectively. The highest cutoff yield was obtained with $F_i^C(V_K)$. At $F_i^C(V_K)$ yield cutoff, 5 of the 84 observations had yield of 6.90 Mg $ha^{-1}$ or more.

Summary statistics for high and low-yielding subpopulations of rice yield and leaf nutrient concentration are given in Table 2. The mean concentration of N, P, K, S, Ca, Mg, Mn and Fe was slightly higher in high-yielding subpopulation than low-yielding subpopulations, however, the difference was greater in case of K. Mean K concentration in high-yielding subpopulation was 14.22 g $kg^{-1}$ compared to 12.19 g $kg^{-1}$ in low-yielding subpopulation. Sufficient range of K in rice at mid-tillering and panicle initiation stage was 1.50 – 2.70 g $kg^{-1}$ (Bell and Kovar 2000). Rice crop in the study area suffered from K deficiency; however, the high-yielding subpopulation had K concentration closer to the lower limit of sufficient range. Observed N, P, S, Ca, Mg, Zn and Mn concentration in the rice plant both in high and low-yielding subpopulations was sufficient, but Fe concentration was above the sufficient range (Bell and Kovar 2000). Although rice plants in the study area contained high concentration of Fe, no toxicity symptom was observed in the field. The nutrient concentration in both high and low-yielding subpopulation showed good symmetry.

Dual ratio of nutrient (Table 3) shows that the N/P, N/K, N/Ca. P/K, and Fe/Mn ratios were greater and N/S, N/Mg, P/S, P/Mg, K/S and K/Mg ratios were lower than the DRIS norms proposed by Bell and Kovar (2000). P/Ca ratio was very close to the DRIS norm. Observed N/K ratio was 105% higher in high-yielding but 174% higher in low-yielding subpopulation than the DRIS norm, which signifies greater imbalance of N and K nutrition in the observed rice plant tissues. Higher N/K ratio in low-yielding subpopulation than the high-yielding subpopulation further confirmed the role of imbalanced N/K ratio in lowering rice yield. Due to low K concentration and optimum P concentration in rice plant tissue, P/K ratio appeared 50% in high-yielding and 66.7% higher in low-yielding subpopulation than the DRIS norm. The P/S ratio was 67.8% lower in high-yielding and 66.7% lower in low-yielding subpopulation than the DRIS norm of 1.8. Higher S concentration in the plant tissue caused this imbalance of P/S ratio. In the both high and low-yielding subpopulation, P/Ca ratio was similar to the DRIS norm of 0.72. The P/Mg ratio showed 37.7% lower in high yielding and 49.5% lower in low-yielding subpopulation than the DRIS norm of 2.12. The K/S ratio was another important nutrient imbalance in rice plant. Compared to the DRIS norm of 16.06, the K/S ratio was 3.48 in high yielding and 3.43 in low yielding subpopulation. Lower K concentration decreased K/Mg ratio by 58.6% in high yielding and 44.7% in low yielding subpopulation compared to DRIS norm of 20.06. Fe/Mn ratio showed the greatest nutritional imbalance in the rice plant. Compared to the DRIS ratio of 0.15, the observed Fe/Mn ratio in high yielding subpopulation was 3.52 and in low yielding subpopulation it was 1.85. However, the higher Fe/Mn ratio in high yielding subpopulation than the low yielding subpopulation signifies that the imbalance due to Fe and Mn did not contribute much to the rice yield.

## Discussion

The cutoff yield of 6.90 obtained for $F_i^C(V_K)$ commensurate to a reasonable good yield for BRRI dhan28, one of the most popular rice varieties, in dry season. The acute K deficiency was indicated both by the highly negative average DRIS K indices and the low average leaf K concentrations. The results of DRIS analyses suggest that inadequacy in K was largely responsible for the underperformance of rice in Piedmont soil. Nutrient concentration and DRIS dual ratio involving K also agreed well that K was the main limiting plant nutrient for rice yield. Soils of the study area had low (0.06 – 0.11 cmol $kg^{-1}$) soil exchangeable K (Saleque et al. 2008). Continual cultivation of rice and removal of rice straw for either fuel or fodder purpose and application lesser K fertilizer than crop removal are the primary factors of K deficiency in the piedmont soils. Soil test based fertilizer application of 47 – 63 kg $ha^{-1}$ K was under dose for piedmont soils.

Potassium play a key role in N uptake and translocation of (Minotti et al. 1968; Cushnahan et al. 1995), and therefore both N and K need to be present in quite specific proportions if N accumulation and subsequent assimilation into protein is to take place at optimal rates (Ramakrishna et al. 2009). Khiari et al. (2001b) compared nutrient concentration, DRIS and CND indexes in sweet corn and found that nutrient concentration values were little to closely related to CND indexes, but the DRIS and CND indexes were highly related to each other. However, DRIS was less effective than CND at separating the high- from low-yield subpopulation of potato (Khiari et al. 2001c). However, critical CND index for rice is not available as of now.

## Conclusion

Generic approach to select a minimum yield target for the high yield subpopulation was found effective for a small database of rice. Potassium inadequacy was the most limiting nutrient factor for rice yield. Potassium fertilizer dose for rice should be increased to improve rice yield in Asia.

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Table 1. Grain yield of rice at inflection points of the cumulative variance functions for row-centered log ratios in the survey population (n = 84)

| Component | $F_i^c(V_x) = aY^3 + bY^2 + cY + d$ | $R^2$ value | Yield at inflection point = $\frac{-b}{3a}$ |
|---|---|---|---|
| N | $1.22Y^3 - 15.89Y^2 + 39.31Y + 85.82$ | 0.99 | 4.33 |
| P | $-0.61Y^3 + 11.77Y^2 - 78.27Y + 181.55$ | 0.73 | 3.26 |
| K | $-1.08Y^3 + 22.44Y^2 - 159.08Y + 390.23$ | 0.98 | 6.90 |
| S | $0.83Y^3 - 9.88Y^2 + 11.14Y + 122.01$ | 1.00 | 3.98 |

Table 2. Summary statistics for rice grain yield and leaf nutrient concentration data for high-yielding (n = 33) and low-yielding (n = 51) subpopulations

| Crop parameter | High-yielding subpopulation ( n = 5) | | | | Low-yielding subpopulation (n = 79) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Min | Max | Skew | Mean | Min | Max | Skew |
| Yield (t ha$^{-1}$) | 7.26 | 6.90 | 7.98 | 0.73 | 4.47 | 1.55 | 6.48 | -0.01 |
| N (g kg$^{-1}$) | 32.66 | 24.10 | 40.50 | -0.14 | 32.41 | 19.60 | 44.40 | 0.01 |
| P (g kg$^{-1}$) | 2.48 | 2.10 | 3.10 | 0.55 | 2.15 | 0.70 | 3.40 | 0.00 |
| K (g kg$^{-1}$) | 14.22 | 11.10 | 16.30 | -0.5 | 12.19 | 2.00 | 18.00 | 0.01 |
| S (g kg$^{-1}$) | 4.60 | 3.10 | 6.50 | 0.14 | 3.75 | 1.50 | 7.50 | -0.01 |
| Ca (g kg$^{-1}$) | 3.54 | 3.00 | 4.10 | 0.16 | 3.11 | 1.00 | 4.90 | 0.01 |
| Mg (g kg$^{-1}$) | 2.42 | 1.00 | 4.90 | 0.6 | 2.30 | 0.80 | 4.20 | 0.05 |
| Zn (mg kg$^{-1}$) | 55 | 51 | 60 | 0.29 | 53 | 51 | 63 | 0.07 |
| Mn (mg kg$^{-1}$) | 638 | 90 | 1328 | 0.25 | 562 | 115 | 1410 | -0.01 |
| Fe (mg kg$^{-1}$) | 836 | 435 | 1066 | -0.48 | 769 | 36 | 2000 | -0.07 |

Table 3. Mean values of nutrient ratios for high and low-yielding subpopulations together with their respective coefficients of variance (CV's), standard deviation and skewness

| Nutrient ratio | High-yield subpopulation ( n = 5) | | | | Low-yielding subpopulation ( n = 79) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | CV (%) | Skewness | Mean | SD | CV (%) | Skewness |
| N/P | 13.30 | 2.39 | 17.94 | -0.54 | 16.43 | 6.46 | 39.31 | 0.01 |
| N/K | 2.30 | 0.29 | 12.83 | 0.73 | 3.07 | 1.91 | 62.37 | 0.00 |
| N/S | 7.85 | 2.82 | 35.98 | -0.41 | 9.26 | 3.09 | 33.33 | 0.02 |
| N/Ca | 9.36 | 1.91 | 20.40 | -1.18 | 11.38 | 4.82 | 42.33 | 0.02 |
| N/Mg | 18.60 | 10.8 | 58.07 | 0.20 | 16.54 | 8.02 | 48.52 | -0.01 |
| P/K | 0.18 | 0.04 | 23.59 | -0.08 | 0.20 | 0.14 | 68.50 | 0.02 |
| P/S | 0.58 | 0.16 | 28.31 | 0.27 | 0.60 | 0.19 | 31.49 | -0.03 |
| P/Ca | 0.70 | 0.06 | 8.19 | -0.18 | 0.73 | 0.29 | 39.87 | 0.03 |
| P/Mg | 1.32 | 0.62 | 46.82 | 0.15 | 1.07 | 0.50 | 47.21 | 0.04 |
| K/S | 3.48 | 1.44 | 41.37 | -0.02 | 3.43 | 1.15 | 33.59 | 0.00 |
| K/Ca | 4.12 | 1.02 | 24.73 | -0.04 | 4.26 | 1.99 | 46.87 | -0.02 |
| K/Mg | 8.31 | 5.24 | 63.06 | 0.24 | 6.20 | 3.20 | 51.61 | -0.04 |
| S/Ca | 1.27 | 0.29 | 22.56 | 0.00 | 1.29 | 0.62 | 48.01 | -0.01 |
| S/Mg | 2.31 | 1.17 | 50.59 | 1.04 | 1.82 | 0.70 | 38.49 | -0.01 |
| Ca/Mg | 1.88 | 0.93 | 49.38 | 0.48 | 1.48 | 0.49 | 33.35 | 0.03 |
| Fe/Mn | 3.52 | 4.43 | 125.96 | 1.09 | 1.85 | 1.96 | 106.14 | 0.03 |