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Yields gap evaluation of wheat grown in Piedmont plain and Floodplain soils of Bangladesh through compositional nutrient diagnosis (CND) norm

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Abstract— *Mineral nutrient stress is one of the major yield gap factors, especially in floodplain and piedmont plain soil. The compositional nutrient diagnosis (CND) provides a plant nutrient imbalance index in statistical distribution patterns, which is important for adjusting the soil-plant systems specific fertilization for maintaining sustainable soil fertility. This study calculated the CND norms of wheat (Triticum aestivum L.) and identified optimum wheat yield target of high-yielding subpopulation in farmers' fields. It also categorized the most yield limiting nutrient(s) for wheat grown. Popular high-yielding wheat was grown in 62 farmers' fields, maintaining farmers' nutrient management plan (FP) and improved nutrient management plan (INM). Nutrient composition analysis was done from 62 young foliar composite samples, collected at 7th leaves stage (vegetative stage). The CND generic model gave 3.47 Mg ha*$^{-1}$ *as minimum cutoff yield of the high-yield subpopulation. Nitrogen was identified as the core yield limiting nutrient for wheat in piedmont and floodplain soils. However, the yield limiting nutrients for wheat grown in the studied are were established the following series: N > S > K, Mg > P, Ca and Mn >Fe >B >Zn respectively. The CND generic model, allowed us to suggest that N, P, K, Mn, B were the factors discriminating high- from low–yielding subpopulation in piedmont plain and floodplain soils of Bangladesh.*

***Keywords—* Compositional nutrient diagnosis (CND), wheat, piedmont plain, floodplain.**

I. INTRODUCTION

Bangladesh is an agrarian country having three dominant physiographic soil types includes floodplain, terrace and hilly area. Among these land types, floodplain and piedmont plain soil have a greater intensification of agriculture. Yield potential of currently cultivated cultivars in a farmer's field decreased due to rigorous cultivation. Thus, mineral nutrient constraint might be one of the major yield limiting factors for farmer's field. Although evaluations of local scale yield limiting factors are essential for ensuring food security but little attempt was taken. Moreover, tropical climatic situation and multiple geomorphic features of Indo-Gangetic region favor higher nitrogen loss and high P and K fixation admits larger nutrient deficient soil, thus more fertilizer inputs are required for intensive cropping system (Timsina and Connor, 2001; Ali *et al.*, 1997). Several evidence also showed that available K concentration of floodplain and piedmont plain soil store < 0.1 meq/100 g soil and mean annual balance of P was found -1 to -9 kg ha^{-1} (Saleque *et al.*, 2006; Panaullah *et al.*, 2006). Besides, less conspicuous deficiency symptoms of P and K in wheat compared to the symptoms of N and S retain farmers from applying these fertilizers. Therefore, understanding of multi-environmental soil nutrient dynamics and nutrient absorption, transport accumulation in plant tissue is essential, to improve the nutritional value of the plant and reducing the yield gap (Mattos *et al.*, 2003; Vargas *et al.*, 2013).

Leaf analysis is a good tool to monitor, evaluate and adjust agricultural fertilization programs to reduce the yield gap (Tomio et al., 2015; Cunha et al., 2016). Because, the leaf is the prime portion of plant that reflect any stresses. Foliar nutrient status can be diagnosed by mineral composition analysis and several mathematical approaches like- Critical Value Approach (CVA) (Bates, 1971), Diagnosis and Recommendation Integrated System (DRIS) (Walworth and Sumner, 1987), and Compositional Nutrient Diagnosis (CND) (Parent *et al.*, 1994). Among these methods, CND approaches, calculate nutrient balance considering all foliar nutrient elements and their interactions and dry mass of plants, provide greater accuracy of diagnosis (Cunha et al., 2013). For selecting suitable nutrient norms, an arbitrarily yield cutoff value is needed for defining a high yield subpopulation (Khiari *et al.*, 2001). Parent and Dafir (1992) and Parent *et al.*, (1994) proposed the X^2 distribution function to define a CND threshold value for nutrient imbalance when relating yield and the cumulative variance ratio function for each nutrient. The CND approach has a robust mathematical basis to define a minimum yield target useful for discriminating between high and low yield subpopulations for identifying specific element related yield gap. Thus, the CND approach is applicable for solving nutrient imbalance problems in specific physiographic unit soil (Khiari et al., 2001).

In Bangladesh, wheat (*Triticum aestivum* L.) is commonly grown in rice-wheat cropping patterns during the “rabi” season from October to March. It is the region’s second most important food security crop after rice (Debnath *et al.*, 2011; Krupnik *et al.*, 2015). The consumption of wheat is increasing due to increase in food diversity in the country. Currently, per capita wheat demand is a 17.3 kg year^{-1}, which is approximately 20% of rice consumption. With 3% more protein than rice, wheat makes an important contribution to per capita protein intake at 4.3 g day^{-1} (FAOSTAT, 2014). Production of wheat is increasing day by day, although the country still imports significant quantities of wheat to meet the rapidly growing domestic demand. Nutrient constraints present in Bangladesh soil become prime yield limiting problem in wheat growing areas especially piedmont and floodplain soils. However, a big knowledge gap is detected in the area of demarcating nutrient based yield gap in the farmer’s field of Bangladesh. Although several nutrient diagnosis approaches were identified for nutrient balance in relation to yield of conifer seedling, onion, garlic, pepper, potato and fruits (Parent *et al.*, 1995; Cunha *et al.*, 2016). Among the different methods, the CND approach was identified as an effective multivariate for distinguishing yield gap by considering the leaf nutritional disorder (Cunha *et al.*, 2016). At present it is fact that there is no information about the nutrient diagnosis approach for wheat in farmers’ fields in floodplain and piedmont plain soil.

Considering the facts, the study was intended the compositional nutrient diagnosis (CND) norms of wheat (*Triticum aestivum* L.) and identifies optimum wheat yield target of high-yielding subpopulation in farmer's fields and nutritional interaction between high and low yielding subpopulation. Moreover, it also categorizes the most limiting nutrient(s) that should be applied to reduce the yield gap of wheat in the region.

II. MATERIAL AND METHODS

Experimental data

This study was conducted based on the data acquired from dry season irrigated wheat plant grown in 62 farmers' fields, in three different districts (Rangpur, Dinajpur and Nilphamari) of northern part of Bangladesh. This area is located between 25°50′N to 89°00′E which incorporate three agro-ecological zones of Bangladesh i.e., Old Himalayan piedmont plain, Active Tista floodplain and Tista meander floodplain. Two nutrient-management practices were tested. The plan-included farmer's practice (FP), which constituted farmer's traditional nutrient management program and improved nutrient management plan (INM). Sixty-two farmer's practices field was randomly selected within the study area. The nutrient doses in farmer's practice field were varied from place to place. For FP, doses of N, P and K varied from 48-114, 8-25 and 0-19 kg ha^{-1} respectively. Twelve experimental field was managed according to soil test based improved nutrient management system (INM). The doses of N, P and K in INM followed field varied from 81-160, 23-39 and 55-97 kg/ha respectively.

At 7th leaves stage 30 young leaves of each experimental plot was collected to prepare foliar composite sample. A total of 62 foliar composite samples were collected from randomly chosen healthy plants at 45-50 days after sowing (DAS). For determining nutrient concentration, each sample was taken from the most recent expanded leaf (immediately before the flag leaf), collected from the standing crops of farmer's field. The leaf sample were dried at 69^{o}C for72 hours and grinned by Wiley mill. The total N content was determined by micro Kjeldahl method (Yoshida *et al.*, 1976). The concentration of K, Ca, Mg, S, Na, Zn, Fe, Mn and B were analyzed by digesting 0.5 g of the leaf sample with 10ml 5:2 HNO_3: $HClO_4$ (Yoshida *et al.*, 1976). P was estimated colorimetrically by the phospho-molybdate blue complex method (Chapman and Parker,1961). For calculating the yield 1m^2 area of each plot was harvested after complete maturity and separated the unfilled grain. Then the nutrient data set were matched with the yield of the same field. Descriptive statistics were determined for leaf nutrient concentration and nutrient ratio expression data. Compositional nutrient diagnosis norms were calculated using Microsoft Excel 2000 Software (Microsoft Corp., 2000).

Theory of the CND approach

To calculate the preliminary compositional nutrient diagnosis norms, we used the CND approach, which has been described in Khiari *et al.*, (2001a). The approach is based on the plant tissue composition, which forms a *d*-dimensional nutrient arrangement, i.e., simplex (*Sd*) made of *d* + 1 nutrient proportions including *d* nutrients and a filling value defined as *R* (Parent and Dafir, 1992). The theory is applied as follows:

$S^d = [(N, P, K, \text{-------} -Rd): N > 0, P > 0, K > 0, Rd > 0, N + P + K + \cdot\cdot\cdot + Rd = 100]$ (1)

Where S^d is simplex made of d nutrient, 100 is the dry matter concentration (%); N, P, K... are nutrient proportions and R_d is the filling value between 100% and the sum of d nutrient proportion computed as follows;

$Rd = 100 - (N + P + K + \cdot\cdot\cdot)$. (2)

The nutrient proportions become scale invariant after they have been divided by the geometric mean (G) of the $d + 1$ components, including Rd (Aitchison, 1986), as follows:

$G = [N \cdot P \cdot K \cdot \cdot \cdot Rd]\ 1/d+1$. (3)

Row-centered log rations are computed as follows:

$V_N = 1n\left(\frac{N}{G}\right)$, $V_p = \left(\frac{P}{G}\right)$, $V_K = \left(\frac{K}{G}\right)$ ..., $V_{Rd} = \left(\frac{Rd}{G}\right)$

(4)

and

$V_N + V_p + V_K + \;..+ V_{Rd} = 0$ (5)

Where, $V_X$is the CND row-centered log ratio expression for nutrient X. The sum of tissue components is 100%, as in equation (1), and the sum of their row-centered log ratios including the filling value must be zero, as in equation (5). Thereafter, the database is partitioned between two subpopulations using the Cate–Nelson procedure, once the observations have been ranked in a decreasing yield order (Khiari *et al.*, 2001). At each iteration, the group A comprises n_1 observations, and the group B comprises n_2 observations for a total of n observations ($n = n_1 + n_2$) in the whole database. For the two subpopulations, the variance of the CND V_X value must be computed. The variance ratio for component X can be estimated as:

$$f_1(V_x) = \frac{Varianceof\ V_x\ n_1\ observations}{Varianceof\ V_x\ n_2\ obervations} \text{ --------(6)}$$

Where$f_1(V_x)$ is the ratio function between two subpopulations, for nutrient X at the ith iteration (i=n$_i$-1) and the V_x is the CND row-centered log ratio expression for nutrient X.

The cumulative variance ratio function is the sum of variance ratios at the ith iteration from top. The cumulative variance ratio function $F^C i\ (VX)$ can then be computed (Khiari *et al.*, 2001) as:

$$F^c{}_i(V_x) = \left[\frac{\sum_{i=1}^{n_1-1} fi(Vx)}{\sum_{i=1}^{n_1-1} fi(Vx)}\right][100] \text{ ………… (7)}$$

is partition number and n is total number of observations (n_1+n_2). The denomination is the sum of variance ratios across all iterations and thus is a constant for nutrient X.

The cumulative function $F^c{}_1\ (V_x)$ related to yield (Y) shows a cubic pattern:

$F^c i(V_x) = aY^3 + bY^2 + cY + d$……………..(8)

The inflection point is the point where the model shows a change in concavity. It is obtained by delving equation [8] twice:

$$\frac{\partial F^C i(Vx)}{\partial Y} = 3aY^2 + 2bY + C \text{………………(9)}$$

$$\frac{\partial^2 F^C i(Vx)}{\partial Y} = 6aY + 2b \text{………………..(10)}$$

The infection point is then obtained by equating the second derivative of equation (10) to zero. Thus the solution for the yield cutoff value is $-b/3a$. The highest yield cutoff values across nutrient expressions (N, P, K and S) were selected to ascertain the minimum yield target for a high yield subpopulation. CND norms were computed using means and standard deviations corresponding to the row-centered log ratios V_X of d nutrients for high-yield specimens.

III. RESULTS

The compositional nutrient diagnosis norms comprised the eleven nutrients and the filling value R. Nutrient concentrations were transformed into CND row-centered log ratios V_N, V_P, V_K, V_{Ca}, V_{Mg}, V_S, V_{Mo}, V_{Zn}, V_{Mn} V_{Fe}, V_B and VRd through equations (1–4). Equation (7) was used to calculate the cumulative variance ratio functions [F^ci (VN)] values.

Table 1. Grain Yield of wheat at inflection points of the cumulative variance functions for row-centered log ratios in the survey population (n=62)

Components	$F_i^c(V_x) = aY^3 + bY^2 + cY + d$	R^2 Value	Yield at inflection point = -b/3a (Mg ha^{-1})
N	$-63.18Y^3 + 657.18Y^2 - 2253.8Y + 2549.9$	0.90	3.47
P	$-84.406Y^3 + 832.71Y^2 - 2683.6Y + 2823.5$	0.75	3.29
K	$-71.818Y^3 + 729.82Y^2 – 2442.3Y + 2696.5$	0.93	3.39
S	$-74.523Y^3 + 771.32Y^2 – 2628.6Y + 2949.8$	0.85	3.45
Ca	$-74.712Y^3 + 738.49Y^2 – 2388.2Y + 2527.9$	0.76	3.29
Mg	$-79.062Y^3 + 738.49Y^2 – 2388.2Y + 2527.9$	0.92	3.39
Zn	$-86.33Y^3 + 870.62Y^2 – 2881.5Y + 3130.3$	0.92	3.36
Mn	$-53.847Y^3 + 8553.67Y^2 – 1883.6Y + 2129.1$	0.92	3.43
Fe	$-78.109Y^3 + 800.77Y^2 – 2700.8Y + 2997.7$	0.89	3.42
B	$-82.82Y^3 + 840.46Y^2 – 2800.7Y + 3064.5$	0.92	3.38
Mo	$-67.078Y^3 + 595.28Y^2 – 2048.3Y + 2327.9$	0.77	2.96
Rd	$-61.20Y^3 + 603.59Y^2 – 1946.2Y + 2052.1$	0.61	3.28

The cutoff yield between the low and high-yield subpopulations were determined after examining the eleven cumulative variance ratio functions [$F^ci(V_N)$, $F^ci(V_P)$, $F^ci(V_K)$, $F^ci(V_S)$, $F^ci(V_{Ca})$, $F^ci(V_{Mg})$, $F^ci(V_{Mo})$, $F^ci(V_{Zn})$, $F^ci(V_{Mn})$, $F^ci(V_{Fe})$ and $F^ci(V_B)$] related to yield. (Table 1 and Fig. 1, Fig. 2 and Fig. 3).

The cutoff yield between the low and high yielding subpopulations obtained fromcumulative variance ratio functions of nitrogen, phosphorus, potassium and sulfur ranged from 3.29 to 3.47 Mg ha^{-1} (Fig. 1 and 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 $F^ci(V_x)$ to zero were 3.47 Mg ha^{-1} for $F^ci(V_N)$, 3.29 Mg ha^{-1} for $F^ci(V_P)$, 3.39 Mg ha^{-1} for $F^ci(V_K)$, 3.45 Mg ha^{-1} for $F^ci(V_S)$, 3.29 Mg ha^{-1} for $Fi^c(V_{Ca})$, 3.39 Mg ha^{-1} for $Fi^c(V_{Mg})$, 3.48 Mg ha^{-1} for $F^ci(V_{Mo})$,, 3.36 Mg ha^{-1} for $F^ci(V_{Zn})$, 3.43 Mg ha^{-1} for $F^ci(V_{Mn})$, 3.42 Mg ha^{-1} for $F^ci(V_{Fe})$ and 3.38 for $F^ci(V_B)$ respectively. The highest cutoff yield was obtained with $F^ci(V_N)$ and $F^ci(V_{Mo})$. At $F^ci(V_N)$ yield cutoff, 5 to 42 observations had yield of 3.47Mg ha^{-1} or more.

Summary statistics for high and low yielding subpopulations of wheat yield and leaf nutrient concentration are given in

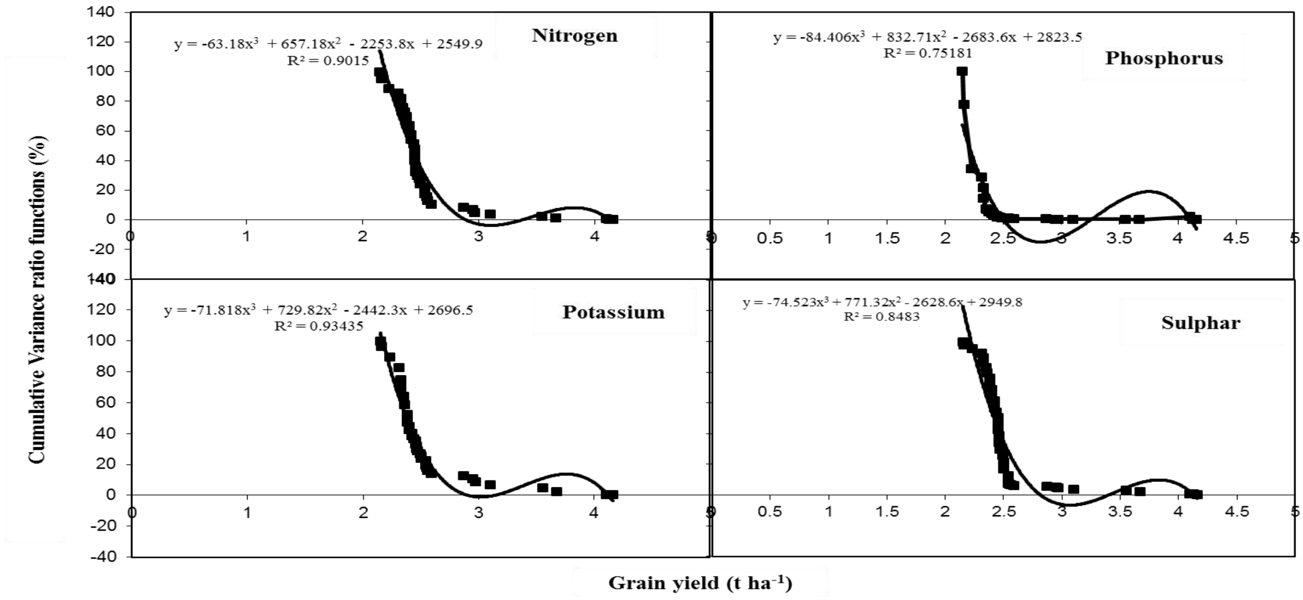

Fig. 1 Relationship between grain yield and cumulative variance ratio function percentage in N, P, K and S for wheat in farmer's fields

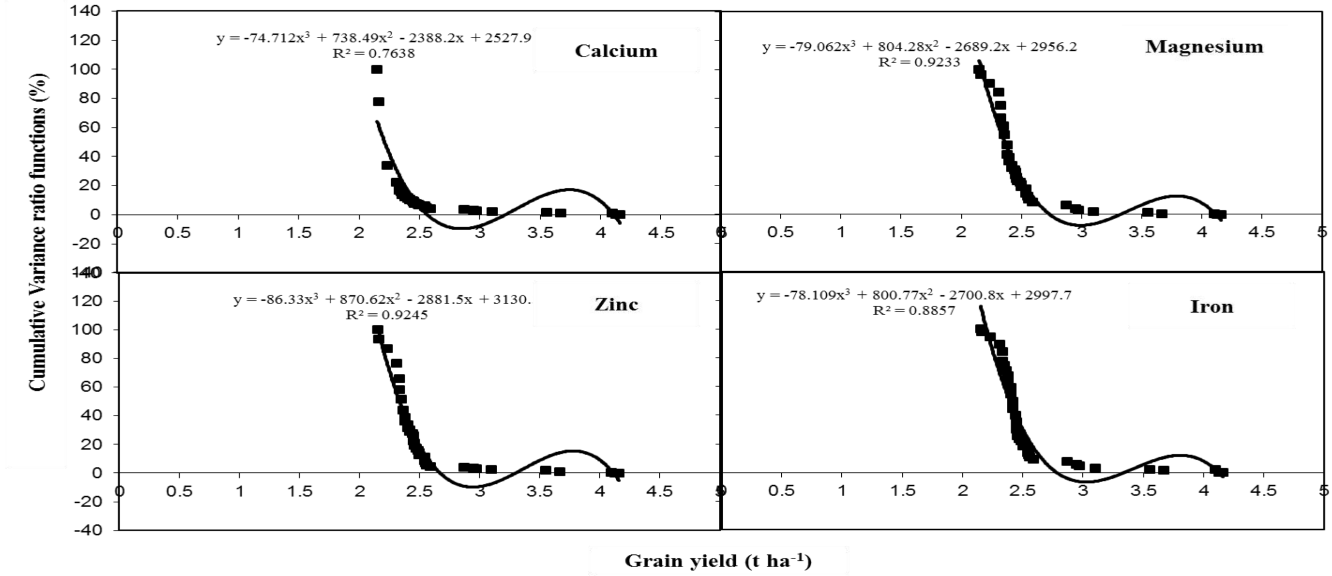

Fig. 2 Relationship between grain yield and cumulative variance ratio function percentage Ca, Mg, Zn and Fe for wheat in farmer's fields

Table 2. The mean concentration of N, P, K, S, Ca, Mg, Mn and Fe was slightly higher in high yielding subpopulations, however, the differences was greater in case of N. Mean N concentration in high yielding subpopulation was 32.22 g kg^{-1} compared to 18.04 g kg^{-1} in low yielding subpopulation. Mean concentration of K, both high and low-yielding subpopulations were only 5.42 and 4.48 g kg^{-1} respectively. The nutrient concentration in both high and low-yielding subpopulation showed good symmetry. Skewness in the high-yielding subpopulation varied from –0.82 in case of S to 2.20 in Mn. In low-yielding subpopulation, varied from –0.12 in case of K to 1.34 in Mg.

Table 3 summarizes the significant nutrient inter-correlations identified in previous section but expressed as nutrient ratios. With the aim of elucidating if these expressions are important to differentiate between the subpopulations, an F-test was performed for each of them.

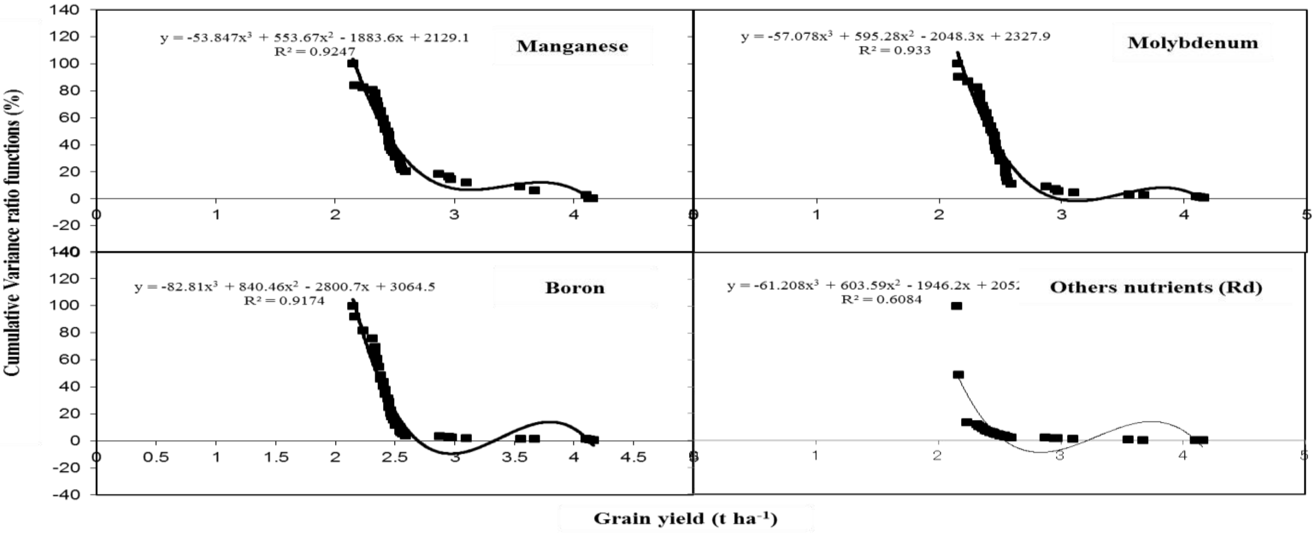

Fig. 3 Relationship between grain yield and cumulative variance ratio function percentage in Mn, Mo, B, and Rd for wheat in farmer's fields

Molar ratio of nutrient showed a big difference between high yielding and low-yielding subpopulation.

Molar ratio of nutrient (Table 3) showed that, the N/K, N/Ca, P/K, P/Ca, P/Mg and Fe/Mn ratios were greater whereas, N/P, N/S, N/Mg, P/S, K/S K/Ca, K/Mg, S/Ca, S/Mg and Ca/Mg ratios were lower than the DRIS norms for rice proposed by Bell and Kovar (2000). N/Mg ratio was very close to the DRIS norm for rice. The observed N/P ratio was 40.06% lower in high-yielding subpopulation and 53.21% lower in low-yielding subpopulation than the DRIS norm for rice. Coefficient of variation of the N/P ratio was 26.34% in high-yielding subpopulation and 43.88% in low-yielding

Table 2. Summary statistics for wheat grain yield and leaf nutrient concentration data for high-yielding (n = 12) and low-yielding (n = 50) subpopulations

Parameters	High yielding sub-population (n=12)					Low yielding sub-population (n=50)				
	Mean	Median	Minimum	Maximum	Skewness	Mean	Median	Minimum	Maximum	Skewness
Yield (t ha^{-1})	3.92	4.10	3.55	4.16	-0.68	2.45	2.45	1.95	3.10	0.78
N (g kg^{-1})	32.22	31.10	29.70	38.00	2.00	18.04	17.70	9.80	29.70	0.50
P (g kg^{-1})	5.72	5.90	3.70	6.70	-1.42	4.29	4.20	2.00	6.80	0.22
K (g kg^{-1})	5.42	5.40	4.50	6.50	0.28	4.48	4.40	0.90	7.70	-0.12
S (g kg^{-1})	5.24	6.20	2.50	6.90	-0.82	3.27	2.90	0.78	8.60	1.32
Ca (g kg^{-1})	1.85	1.94	1.40	2.03	-2.09	1.48	1.40	0.34	3.50	0.79
Mg (g kg^{-1})	0.24	0.20	0.20	0.30	0.61	0.38	0.30	0.10	1.10	1.34
Zn (g kg^{-1})	0.03	0.03	0.02	0.04	-1.92	0.03	0.03	0.01	0.04	0.58
Mn (g kg^{-1})	0.06	0.04	0.03	0.15	2.20	0.09	0.07	0.02	0.19	0.20
Fe (g kg^{-1})	0.24	0.20	0.20	0.35	1.89	0.32	0.28	0.20	0.49	0.50
B (g kg^{-1})	0.05	0.05	0.05	0.06	0.61	0.07	0.07	0.05	0.10	0.86
Mo (g kg^{-1})	0.01	0.01	0.01	0.01	1.07	0.01	0.01	0.01	0.01	-0.32

subpopulation. Skewness of N/P ratio was 1.68 in high-yielding and 0.96 in low-yielding subpopulation. Observed N/K ratio was 90.75% higher in high-yielding and 61.34% lower in low-yielding subpopulation than the DRIS norm for rice, which signifies greater imbalance of N and K nutrition in the observed wheat plant. Higher N/K ratio in the high-yielding subpopulation than the low-yielding subpopulation further confirmed the role of imbalanced N/K ratio in lowering wheat yield. The N/S ratio was 65.27% lower in high-yielding and 69.73 % lower in low-yielding subpopulation than the DRIS norm for rice. N/Ca ratio was 4.43% higher in high-yielding and 6.01% higher low-yielding subpopulation than the norm of 6.77. The N/Mg ratio was very close to the DRIS norm of 19.72, only 10.5% lower in high-yielding and 21.90% lower in low-yielding subpopulation. Due to low K concentration and optimum P concentration in wheat plant tissue, P/K ratio appeared 233.3% in high-yielding and 175% higher in low-yielding subpopulation than the DRIS norm for rice. The P/S ratio was 40.55% lower in high-yielding and 33.33% lower in low-yielding subpopulation than the DRIS norm of 1.8 for rice. Higher S concentration in the plant tissue caused this imbalance of P/S ratio. In both high and low-yielding subpopulations, P/Ca ratio was higher over 65.28% and 136.11% to the DRIS norm of 0.72. The P/Mg ratio showed 44.34% higher in high yielding and 64.62% higher in low-yielding subpopulation than the DRIS norm of 2.12 for rice. The K/S ratio was another important nutrient imbalance in wheat plant. Compared to the DRIS norm for rice of 16.06, the K/S ratio was 2.66 in high yielding and 3.81 in low yielding subpopulation. Lower K concentration decreased K/Mg ratio by 61.11% in high yielding and 44.41% in low yielding subpopulation compared to DRIS norm of 20.06 for rice. Compared to the DRIS ratio of 0.15 for rice, the observed Fe/Mn ratio in high yielding subpopulation was 5.06 and in low yielding subpopulation it was 6.17. 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

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

Molar ratio	High yielding sub-population (n=12)				Low yielding sub-population (n=50)				F-ratio	Mean Reference Molar ratio
	Mean	SD	CV (%)	Skewness	Mean	SD	CV (%)	Skewness		
N/P	5.88	1.55	26.34	1.68	4.59	2.01	43.88	0.96	1.73	8.24
N/K	2.27	0.23	10.27	1.6	1.39	0.46	33.15	0.48	16.84	0.21
N/S	6.00	0.58	9.62	0.49	5.23	3.74	71.65	1.90	0.16	9.92
N/Ca	7.07	3.31	46.8	1.61	7.16	5.37	75.06	2.42	0.01	6.76
N/Mg	17.65	3.01	17.07	1.39	15.40	11.67	75.77	2.39	0.16	19.72
P/K	0.40	0.08	20.75	-1.32	0.33	0.10	30.21	0.15	2.29	0.93
P/S	1.07	0.27	25.18	-0.39	1.20	0.76	63.78	1.74	0.13	1.80
P/Ca	1.19	0.39	32.33	0.74	1.70	1.18	96.48	2.43	6.12	0.72
P/Mg	3.06	0.34	11	0.16	3.49	2.21	63.26	2.62	0.18	2.12
K/S	2.66	0.35	13.15	-0.13	3.81	2.49	65.26	1.83	1.01	16.06
K/Ca	3.14	1.49	47.49	1.44	5.17	3.18	61.65	2.35	1.87	6.23
K/Mg	7.80	1.21	15.45	2.09	11.15	7.55	67.72	2.60	0.94	20.06
S/Ca	1.19	0.57	48.31	1.7	1.77	1.48	83.49	3.03	0.72	0.68
S/Mg	2.97	0.61	20.5	0.6	3.65	2.22	60.86	0.74	0.44	1.99
Ca/Mg	2.76	0.79	28.58	-0.58	2.70	1.90	71.34	1.72	0.01	2.92
Fe/Mn	5.06	1.49	29.42	-2.17	6.17	5.97	96.75	2.18	0.16	0.15

to the wheat yield. Compositional nutrient diagnosis (CND) row-centered log ratio (V_X) for N, P, K, Ca, Mg, S, Zn, Fe and Mn are presented in Table 4. The high and low-yielding subpopulation had V_N 2.43 and 2.02, V_P 0.97 and 0.78, V_K 2.15 and 2.31, V_{Ca} 0.64 and 0.12, V_{Mg} – 0.12 and – 0.19, V_S 0.97 and 0.50, V_{Zn}– 4.14 and – 3.97, V_{Mn} – 3.08 and – 2.42, V_{Fe} – 1.60 and – 1.20 and V_B -3.09 and -3.10. Difference in V_X was not large for any of the tested nutrient between high and low-yielding subpopulation.

Table 4. Compositional nutrient diagnosis (CND) row-centered log ratio of nutrients with their standard deviation and coefficient of variation (CVs)

Row-centered log ratio	High yielding sub-population (n=12)			Low yielding sub-population (n=50)		
	Mean	SD	CV(%)	Mean	SD	CV (%)
V_N	2.43	0.34	14.04	2.02	0.16	8.07
V_P	0.97	0.3	31.36	0.78	0.13	17.22
V_K	2.15	0.17	7.97	2.31	0.13	5.56
V_{Ca}	0.64	0.48	75.18	0.12	0.37	306.03
V_{Mg}	-0.12	0.39	-28.87	-0.19	0.06	-32.88
V_S	0.97	0.48	49.43	0.5	0.2	39.92
V_{Zn}	-4.14	0.32	-7.76	-3.97	0.24	-6.02
V_{Mn}	-3.08	0.66	-21.30	-2.42	0.55	-22.78
V_{Fe}	-1.60	0.3	-18.5	-1.2	0.19	-15.63
V_B	-3.09	0.27	-8.74	-3.1	0.1	-3.31
V_{Mo}	-1.58	0.6	38	-1.42	0.25	-17.54
V_{Rs}	6.45	0.18	2.71	6.59	0.14	2.17

IV. DISCUSSION

The CND norms of nutrients

The CND norms were derived from high yielding sub-population and low-yielding sub-population farmer's field yield of wheat. Nutrient concentrations that were transformed into row-centered log ratios were used for the derivation of CND norms. There was however a significant difference in the mean row centered log ratios for the high and low-yielding sub populations, suggesting that the yield difference is due to nutritional disorder (Nkengafac and Ejolle, 2014). These obtained nutrient norms helps to nutrient assessment in wheat grown in Piedmont and Floodplain soil. Yield depended database shown that for nitrogen the cutoff yield was 3.47 Mg ha^{-1} indicates commensurate to a reasonable good yield for wheat (Table 1). Thus, it is most likely that N was the most limiting nutrient of yield, as this was evidenced by a significant negative correlation between N and yield (data not shown) when considering low performance observations. However, the cutoff yield for $F^c i$ (V_S), $F^c i$ (V_K) were 3.45 and 3.39 Mg ha^{-1} respectively also matching to a reasonable good yield for wheat (Table 1). This trends suggests that K and S also limited the yield of wheat considered as experimental unit, which can be interpreted as insufficiency of this nutrient, especially in the subpopulation of low yields. The acute K deficiency was indicated by highly negative average CND, K indices and the low average leaf K concentrations. The results of CND analyses suggest that inadequacy in K was largely responsible for the underperformance of wheat in piedmont and floodplain soils of Bangladesh. Nutrient concentration and CND dual and or molar ratio involving K also agreed well that K was the main limiting plant nutrient for wheat yield. Continual cultivation of wheat- rice cropping and removal of 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 55-97 kg ha^{-1} K was under dose for piedmont and floodplain soils of Bangladesh. Under dose of K fertilizer application create a negative K balance in rice – wheat cropping (Timsina et al., 2006). Depletion of soil nutrients, particularly K, is a possible cause of yield decline in long-term experiments in northwest India (Bhandari *et al.*, 2003). Saleque et al. (1998b) reported an economic optimum dose of K fertilizer of about 80 kg ha^{-1} in Barind soil of Bangladesh. Potassium play a key role in N uptake and translocation of (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). Moreover, the studied area contained high concentration of P but low amount of Mg indicates non-calcareous alluvium soil in nature (García -Hernández, et al., 2007).

Nutrient molar and or dual ratio

The molar ratios of different nutrients are used as a simple indicator of nutrient bioavailability (Zheng et al., 2010). This molar ratio of different nutrients indicates apparent antagonistic and synergetic effects of a particular nutrient on other nutrient in wheat plants (Cunha et al., 2016). However, these study identified that some of molar nutrient ratio become more important for wheat production in Piedmont and Floodplain soil in Bangladesh.

Like this study shown that, the most consistent negative skewness was observed in the Ca/Mg ratio. Several reporters reported that commonly Ca^{2+} is strongly competitive with Mg^{2+}in substrates and often results in increased leaf-Ca along with a marked reduction in leaf Mg (Ruiz *et al.*, 1997; Grattan and Grieve, 1999). Another explanation for leaf Mg deficiency might be absent of Ca-Mg synergism (García -Hernández, *et al.*, 2007; Hernández, *et al.*, 2008). However, this interaction is not important to discriminate between high- and low-yield subpopulations as proved by the F test (Table 3).

However, the N/Ca molar ratio had shown the most consistent positive skewness in this studied area. This finding is strongly disagrees the previous findings by Marschner (1986) who indicated that $NH_4^+$and Ca^{2+} ions are strongly competitive with each other for substrate. But, this interaction was not important in the discrimination between high and low-yield subpopulations as indicated by the F-test (Table 3).

A symmetric skewness was observed in P/Ca molar ratio (Table 4) and with a significant level of the F value (Table 3). This negative relationship may result from higher activity of P in the soil solution due to forming higher solubility of P minerals, especially on soils having lower exchangeable Ca2+, and thus increase P uptake by plants (Barł óg, 2014). There is no robust physiological explanation for the antagonism between N and Mg. This negative interaction has been found in corn leaves by Dara *et al.*, (1992). The ratio between these two nutrients was not prominent to differentiate high- and low-yield datasets using the F-test (Table 3).

In contrast, the symmetric skewness between Ca and P was found to discriminate between high- and low-yield subpopulations as shown by the F test (Table 3). This finding is disagrees with report of Parent *et al.* (1994) who had reported the antagonistic effects of these two nutrients. These trends may be happened due to the sandy and or silty soil type of these areas with low cation exchange capacity. Another important molar ratio was the K/Ca ratio (Table 4). This positive interaction was also useful to differentiate high from low-yield subpopulations (Table 3).

The P/K ratio appeared significant to discriminate high and low-yield subpopulations (Table 3). Sumner and Farina (1986) found that the K–P interaction was important in the forage sorghum production, indicating that the balance between K and P is important.

The N/P ratio, as evidenced by a symmetric skewness between N and P (Table 4) and a significant level of the F-value (Table 3), was important for discriminating the ratio between the low and high- yielding subpopulations. Moreover, it should be pointed out that N–P interactions are probably the most economically important of all interactions involving P (Sumner and Farina, 1986; García -Hernández, *et al.*, 2007).

A symmetric skewness was observed in N/K molar ratio (Table 4) and with a significant level of the F value (Table 3), was the most discriminating ratio between the low- and high- yielding subpopulations. These trends may be happened due to continual cultivation of wheat- rice cropping, application of lesser K fertilizer than crop removal in the piedmont soils. Under dose of K fertilizer application create a negative K balance in rice – wheat cropping (Timsina *et al.*, 2006). These results agreed with findings of Saleque *et al.*, (2008) indicating that soils of the study area had low (0.06 – 0.11 cmol kg^{-1}) soil exchangeable K. Moreover, Timsina *et al.*, (2006) reported that with continual cropping and low application of K fertilizer create a negative K balance in rice – wheat cropping piedmont and floodplain soils of Bangladesh. However, the interpretation of interactions identified by diagnostic techniques, as the multivariate CND approach could help in overcoming some of the drawbacks of the classical approaches.

V. CONCLUSION

Generic approach to select a minimum yield target for the high yield subpopulation was found effective for a small database of wheat. The corresponding optimum ranges of nutrients for wheat gave 3.47 Mg ha^{-1} as minimum cutoff yield of the high-yield subpopulation. According to the model, macro nutrients (N, K and S) and micro nutrients (Mn, B) inadequacy were the major limiting nutrient factor for wheat yield in piedmont and floodplain soils of Bangladesh. Moreover, five interactions were strongly evident for wheat N-K, N-P, P-K, P-Ca, K-Ca, and K-S. Nitrogen, sulphur and potassium fertilizer including some micronutrient i.e., Mn and B dose for wheat should be increased to improve wheat yield in piedmont plain and floodplain soils of Bangladesh.

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CONFLICT OF INTEREST

There is no conflict of interest.

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