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Review article

Techniques of efficient fertilizer management for wetland rice- a review

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Abstract

Efficient fertilizer management was proved as a tool for increased crop production in an environmental friendly way. Nutrient response studies determine optimum economic doses for a particular nutrient under specific soil environment. Fertilizers need assessment entails, soil test results and nutrient response models. A few models for fertilizer rate calculation based on soil test values, are briefly discussed in this paper. The test results from site specific nutrient management (SSNM) model showed about 10% grain yield increase compared to that of farmers' practice in Asia. The results of several studies showed that the use of urea supper granule (USG), leaf color chart (LCC) and Soil Plant Analysis Division: Chlorophyll meter (SPAD) based on N fertilizer management increased N fertilizer use efficiency and reduces environmental risk. The mean yield values of 18 tidal prone sites of Bangladesh showed USG produced an average of 17.84% higher yield of MV rice and saved an average of 32.52% of N over prilled urea. N and K nutrients response in rice were best fitted to quadratic and square root quadratic, while for P response curve it was linear plateau. In clay loam soils of Bangladesh, a linear yield increase was observed from <3 to 6 mg kg^{-1} available P and then leveled-off up to 17 mg kg^{-1}. Potassium fertilizer positive response was found up to 80 kg ha^{-1} of K in clay loam soils of Bangladesh. It can be concluded that for sustainable, efficient and environment-friendly rice production fertilizer application should be based on plant and soil tests, either it derived from different model or crop nutrient response study.

Keywords: Fertilizer model; Nitrogen; Phosphorus; Potassium; Sulfur; Zinc.

Abbreviations:

AEZ	Agro Ecological Zone
Boro	Rice growing season (Irrigated)
BCSR	Basic Cation Saturarion Ratio
IPUE	Internal Phosphorus Use Efficiency
IRRI	International Rice Research Institute
LCC	Leaf Color Chart
QUEFTS	Quantitative Evaluation of Fertility for Tropical Soils
SAS	Statistical Analyses System
SLAN	Sufficiency Level of Available Nutrient
SPAD	Soil Plant Analysis Division: Chlorophyll meter
SSNM	Site Specific Nutrient Management
T. Aman	Transplanted Aman rice growing season (Rain fed)
USG	Urea Super Granule

Introduction

Fertilizer management issue in rice production is drawing attention among farmers, especially under current climate change situation. Efficient fertilizer management under environment-friendly condition is crucial to increase rice production worldwide. Appropriate amount of fertilizers applied onto soils reduced greenhouse gas emissions, NO_3 leaching and eutrophication. World's more than three billion people depend on rice as their staple food (FAO, 2004). Appropriate use of chemical fertilizers is needed to boost rice production and mitigate poverty in Asia. About 50 percent of all mineral fertilizer nutrients are used for the production of cereals (wheat, rice and maize), and 50 percent of total mineral fertilizer nutrients are consumed by China, the United States of America and India. Worldwide mineral fertilizer nutrient use is expected to increase annually about 1.7% from 2007/2008 to 2011/2012, which is an equivalent of about 15 million tons. Among them 69% will take place in Asia and 19% in America (FAO, 2008). The yield plateau of rice and adverse environmental impacts due to imbalance use of chemical fertilizers illustrate worldwide attention for efficient nutrient management. Rice, the staple food for most of the people in South and Southeast Asia, removes about 16 to 19 kg of N, 2.5 to 3.5 kg P and 19 to 25 kg K from soil to produce one tone of rough rice (Dobermann et al., 2000). With the green revolution, the use of chemical fertilizer increases several folds and inefficient use of these fertilizers has resulted in serious environmental consequences. The most adverse environmental impacts in field crops is the depletion of stratospheric ozone due to NO and NO_2 emission. It is known that among the global warming gasses the contribution of NO_2 is 9% of the total, and within this total about 88% comes from agriculture sector (FAO, 2007). Additionally, the production of chemical fertilizers using fossil fuel is another issue of environmental pollution. Besides environmental pollution, farmers are loosing their money due to application of excessive amount of expensive fertilizers. Nowadays, global fertilizer market has become a political issue. In this regard, the resource poor countries of the world need a solution to this predicament. The objective of this paper is to describe efficient ways of using chemical fertilizers for maximal rice production considering the unpredictable climatic condition. Proper soil management practices and especially efficient fertilizer application increase crop yield (Li et al., 2001; Shen, 2002). In sustainable agriculture, nutrient management practices include both crop and soil fertilization. Crop fertilization refers to fertilizer application according to the crop demands, while soil fertilization is targeted to replenish its fertility level. The strategy of efficient fertilizer management program involves precise decision on the right rate, source, time and place of fertilizer application (Bruulsema et al (2009). The amount of fertilizers to be applied for a target yield may be determined by soil testing, nutrient response or missing element trial techniques.

Soil testing

Soil test methods take into consideration major factors and processes relevant to the availability of the particular plant nutrient (Mengel, 1982). Soil variables such as pH, texture and organic matter influence nutrient uptake by plants. Effects of these variables on nutrient uptake along with the soil test results have been studied and estimated by multiple regressions. Multiple regressions have two forms:

(i) Additive model

$$U = a + b_1P + b_2(pH) + b_3(Clay) + b_4(OM)$$

(ii) Interactive model

$$\log U = \log a + b_1 \log P + b_2 \log (pH) + b_3 \log(Clay) + b_4 \log(OM)$$

where, P represents a nutrient such as phosphorus; a is intercept and b1, b2, b3 and b4 are coefficient of the regression equation. Two main concepts of soil test interpretation are sufficiency level of available nutrient (SLAN) and basic cation saturation ratio (BCSR) (McLean, 1977). The SLAN concept is based on the fact that the increase in yield of a crop per unit of available nutrient decreases as the level of available nutrient approaches sufficiency level. The BCSR concept implies that for optimum growth of crops both, best ratio of basic cations and total base saturation exist in a soil. Determination of proper doses of fertilizer is a difficult task as it needs soil test results, estimated yield, crop sequence, farmers' experience, etc. Several models are used to determine nutrient doses from soil test results such as IRRI, BARC, QUEFTS, SSNM, etc.

IRRI model

This model was developed by the International Rice Research Institute, the Philippines, in 1985, especially for rice crop. The required dose of nitrogen may be calculated by the following equation:

$$N_{req} = (40y - 1000S_n)$$

Where, N_{req} = Amount of N required (kg/ha), Y = Expected yield (t/ha), Sn = Soil total N (% w/w)

Four important assumptions of this model include : (i) five percent of total N is mineralized per season; (ii) efficiency of soil and fertilizer N is 50%; (iii) mass of soil in the top 15 cm of a ha of puddled field is 2×10^6 kg; and (iv) twenty (20) kg of N are absorbed per ton of grain production. For calculation of phosphorus and potassium fertilizer doses the required formulae is:

$$Freq = \frac{(Uf - U0)}{R}$$

Where, Freq= Required fertilizer, Uf = Nutrient uptake by crop for desired yield, U0= Nutrient uptake from unfertilized soil and R is the recovery (P = 60% and K= 80%) of applied fertilizer.

BARC (Bangladesh Agricultural Research Council) model

Bangladesh Agriculture Research Council developed this model in 2005 according to soil test-based data. There are 30 agro-ecological zones (AEZ) in Bangladesh (BARC 2005). The soil test values are documented according to AEZ. Farmers can get easily fertilizer doses according to their target yield:

$$F_r = U_f - \left(\frac{C_i}{C_s} - (S_t - L_s) \right)$$

Here, F_r = Fertilizer nutrient required for given soil test value, U_f = Upper limit of the recommended fertilizer nutrient for the respective soil test value interval (STV I) class, C_i = Units of class intervals used for fertilizer nutrient recommendation, C_s = Units of class intervals used for STV I class, S_t = is the Soil test value and L_s is the Lower limit of the soil test value within STV I class.

QUEFTS (Quantitative Evaluation of Fertility for Tropical Soils) model

Quantitative Evaluation of Fertility for Tropical Soils model predicts crop yields from chemical soil characteristics, as an indicator of soil fertility (Janssen et al., 1990). Potential N, P, and K supplying capacities are estimated as:

$$SN = 0.25\ (pH - 3) \times 6.8 \times \text{organic C} \times 10$$

$$SP = ((1 - 0.50\ (pH - 6)^2) \times (0.35 \times \text{organic C} \times 10 \times 1.5\ (\text{Olsen P})$$

$$SK = \frac{\left(0.625(3.4 - 0.4pH) \times 1350 \times exch.K \times 10\right)}{\left(2 + 0.9 \times org.C\right)}$$

SN, SP and SK stands for potential supply of N, P and K, pH is applicable in the range of 4.5 – 7.0, organic C is expressed as %, Olsen P as mg kg^{-1} and exchangeable K in $cmol_c\ kg^{-1}$.

Table 1. Effect of different soil test based fertilizer models on yield of BRRIdhan29 rice variety in Bangladesh

Treatments	Boro season 2002		Boro season 2003	
	Grain yield (t/ha)	Straw yield (t/ha)	Grain yield (t/ha)	Straw yield (t/ha)
Control	4.87	3.72	2.31	2.21
BARC model	6.81	5.54	5.30	4.61
IRRI model	6.94	6.27	5.73	5.01
QUEFTS model	6.66	6.70	6.55	5.19
SSNM model	7.06	7.47	6.11	5.11
LSD (0.05)	0.73	1.18	0.71	0.69
CV (%)	6.2	6.2	7.4	8.4

Source: Bangladesh Rice Research Institute (BRRI) Internal Review report 2002-2003.

Table 2. Performance of Site Specific Nutrient Management SSNM over Farmers Fertilizer Practice (FFP) for four successive rice crop grown in Asia

Sites	*Benefits obtained in SSNM over FFP*			
	Grain yield increased	N uptake	P uptake	K uptake
	(%)			
Maligaya (Philippines)	9.69	16.44	15.26	9.10
Suphan Buri (Thailand)	2.04	5.91	6.11	12.96
Omon Mekong (Vietnam)	6.91	7.19	12.77	17.45
Sukamandi (Java, Indonesia.)	0.22	8.72	10.71	2.68
Aduthurai (Tamil Nadu, India)	4.86	11.15	10.86	9.63
Thanjavur, (Tamil Nadu, India)	7.59	17.91	20.41	15.82
Jinhua (China)	7.08	7.26	11.42	9.07

Source: Dobermann et al. (2002).

Factor 1.5 instead of 0.5 for Olsen P and 1350 instead of 400 for exchangeable K was modified from Janssen et al (1990) to adjust P and K supply for lowland rice soils. Putting the SN, SP and SK values in the following equation, fertilizer N, P, and K requirement may be calculated for an attainable target yield (Y_t):

$$N = \left(\frac{Y_t \times 18 - SN}{0.40} \right), \; P = \left(\frac{Y_t \times 2.5 - SP}{0.25} \right),$$

$$K = \left(\frac{Y_t \times 20 - SK}{0.45} \right)$$

The assumptions of the equation are rice crop absorb 18-20 kg N, 2.5-3 kg P and 19-21 kg K to produce 1 tone of grain and recovery of N, P and K are 40, 25 and 45%, respectively.

SSNM (Site Specific Nutrient Management) model

Site-specific nutrient management technique is useful to determine optimum doses of nutrients (Witt et al., 2007). This SSNM model represents fertilizer dose for a target yield. SSNM provides a field-specific approach for dynamically applying nutrients when crop needed (Pampolino et al., 2007). This can be calculated as:

$$Freq = \frac{(Yf - Y0)\, NU}{R}$$

Where, Freq = Required fertilizer, Yf = is the desired yield (t ha^{-1}), Y0 = is the yield (t ha^{-1}) obtained from unfertilized soil, NU = Nutrient uptake to produce 1 tone grain and R is the recovery of applied fertilizer. This model assumes rice crop absorbs 15 kg of N, 2.6 Kg of P, and 15 kg of K to produce 1 ton of grain. Recovery of N is 40%, P is 20% and K is 60%, respectively.

Evaluations of the models

Field evaluations were carried out to determine the best model to be adopted for wet rice cultivation in Asia. A field experiment was carried out in the Bangladesh Rice Research Institute during period of 2002-2003 to evaluate the performance of a few models mentioned above. Among the models tested, significantly higher yield was obtained from SSNM and QUEFTS models (Table 1). The grain yields among the models were not statistically identical which proved that using any model would not produce significant yield increment. Results of several studies in Asia revealed that SSNM model increased average grain yield and nitrogen fertilizer use efficiency by 30-40% and reduced greenhouse gas emission to a considerable extent (Dobermann et al., 2002; Pampolino et al., 2007). This model was tested at seven intensive rice domains with conventional farmers' fertilizer practice (FFP) for four successive rice crops and found about 10% grain yield was increased compared to farmers' fertilizer practice (Table 2). This model evaluated in farmers' field before 2001 and was also found yield benefit and profit compared to farmers' fertilizer practices (Dawe et al., 2004).

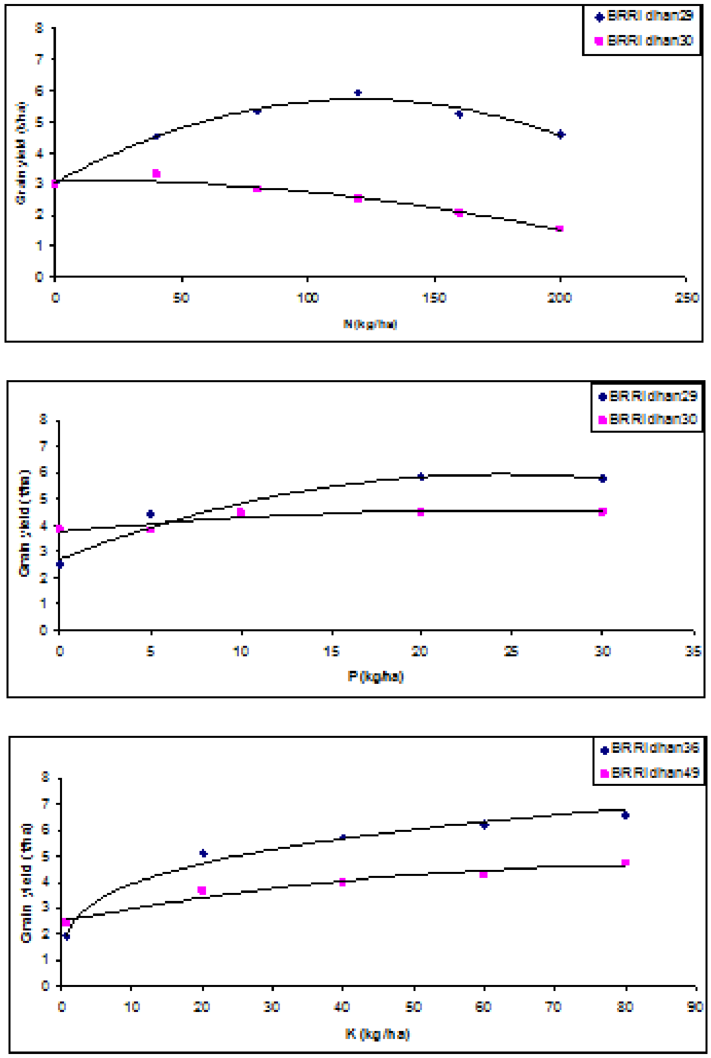

Fig 1. Effect of N, P, K on the grain yield of rice variety BRRI dhan29, BRRI dhan30 and BRRI dhan36 in the two successive rice growing season (Boro and T. Aman season).

Nutrient requirement determination through nutrient response studies

Nutrient response studies are useful for determination of optimum economic dose of a particular nutrient under specific soil and environmental conditions. Proper diagnostic fertilization helps correct nutrient deficiency (Janicki and Jones, 2004). Five of any doses of the nutrient in question are tried in 3 or more replications. Yields of the crop are regressed against applied nutrient doses. Response curve for N and K nutrients are usually quadratic and square root quadratic, while that for P and other immobile nutrients is linear plateau (Fig.1). Economic optimum dose for different functional forms are shown in (Table 3). This model shows that the response of N and P for BRRIdhan29 rice (a modern rice variety in Bangladesh) was 120 kg N ha^{-1}, 15-20 kg P respectively, while for K the response was up to 80 kg K ha^{-1}. Using these models, farmers can calculate economic optimum doses.

Time and methods of application

Fertilizer application should be coincide with crop demand, particularly with growth stage. Right time of fertilizer application will reduce loses of nutrient from soil-plant system. Time and methods of fertilizer application depend on the soil, climate, nutrients and rice variety. A submerged soil condition provides root with an environment which is completely different from non submerged soil (Trolldenier, 1977). Usually, rice crop needs N, P, K, S and Zn fertilizers.

Nitrogen

Nitrogen is the most crucial nutrient for rice production. In submerged rice soil, applied nitrogen fertilizer is prone to loses in several ways. The simulated annual nitrogen losses data showed that about 37% of applied fertilizer nitrogen is loss through several process (De Datta, 1998). The total N losses through several gaseous processes in Neuva Ecija, Philippines shown in Table 4.

Table 3. Different response equations and formulae for calculating optimum fertilizer rate.

Functional forms	Equation	Optimum rate*
Quadratic	$Y = a + bx + cx^2$	$X = \left(\dfrac{E_N - b}{2c}\right)$
Square root quadratic	$Y = a + bx^{0.5} + cx$	$X = \left(\dfrac{0.5b}{E_N - c}\right)^2$
Linear plateau	$Y = a + b(x - c - \lvert x - c \rvert)$	$X = c, \text{if } 2b \geq E_N$

$^* En = \dfrac{P_f}{P_y}$, P_f is Price of fertilizer/kg and P_y is price of rice/kg.

Where, Y represents yield, x is nutrient applied, a, represents as intercept, b and c are coefficient of the regression equation. Pf and Py are price of fertilizer and price of rice, respectively.

Table 4. Assessment of simulated annual N gas loses from N fertilizer application in Nueva Ecija in Philippines

Location	Simulated annual N gas losses		
	Gas	From soil and fertilizer Kg N ha^{-1}	% of N fertilizer
Nueva Ecija	N_2	11.5	3.8
	N_2O	4.5	1.2
	NH_3	81.0	34.0
	NO	2.8	0.9

The total amount of applied nitrogen was 199 kg ha^{-1} (114 kg N in dry and 85 kg N in wet season) applied in two splits (farmer's fertilizer practices) per cropping season. Source: Pampolino et al (2007).

Nitrogen can be lost via volatilization immediately after fertilizer application. Nitrous oxide, the greenhouse gas, is the end product of nitrification and denitrification process that can remove 2.5 kg N ha^{-1} of applied nitrogen annually (Pampolino et al., 2007). Crop demand based fertilizer application can reduce this emission as well as reduction of applied N fertilizer losses. Nitrogen concentration in the leaf at early growth stage is correlated with panicle per m^2. The number of spikelets per panicle and the average nitrogen concentration of leaf blades at 1 to 4 weeks before heading are closely correlated. Therefore, nitrogen should be applied in a way that plant does not suffer from its deficiency at any growth stage. Scientists over the world conducted abundant research on the timing of nitrogen fertilizer application and came out with two options: either three-split application or two-split application. Three-split nitrogen application includes one-third during final land preparation, one-third at mid-tillering stage and the rest at 5-7 days before panicle initiation (DBPI) (Dobermann and Fairhaurst, 2000). For long duration variety (>150 days), the basal dose may be avoided and should be applied at 15-20 days after transplanting provided there is assurance of water availability. The application of N fertilizer increased rice yield to 6.04 t ha^{-1} from 3.33 t ha^{-1} in Boro season, but the effect was minimal in T. Aman season (Fig. 1). Water management is an important issue for nitrogen fertilizer application. Better N use efficiency is obtained if it is applied to muddy soil, followed by incorporation than applied on the standing water. Nitrogen applied during panicle initiation stage need not incorporate with soil because there is sufficient root mass at the aerobic zone of soil. Two split application as 2/3rd basal and 1/3rd DBPI is practiced in the Philippines (Dobermann and Fairhaurst, 2000). IRRI developed another approach that is LCC based application (Furuya, 1987). Application of N fertilizer based on LCC reading save a portion of N and real time N management can be done. Nitrogen use efficiency is expected to increase due to LCC based N management. The leaf chlorophyll content as well as leaf greenness can be determined using portable chlorophyll meter (SPAD). The study result in India showed that plant need–based N management through chlorophyll meter reduces N requirement of rice from 12.5 to 25%, with no loss in yield (Singh et al., 2002). Unlike LCC, uses of SPAD meter reading reduced amount of nitrogenous fertilizer and increased N use efficiency (Table 5). Liquid urea injection at 5-6 cm soil depth can reduce ammonia volatilization loss and increased grain yield and fertilizer N recovery (Schnier, 1994). Urea super granule (USG) if applied instead of urea should be applied at 12 – 15 days of transplanting. USG application also save N fertilizer and increase use efficiency compared to urea. USG application increases nitrogen fertilizer use efficiency in tidal prone areas in Bangladesh. A number of 16 experiments were conducted in farmer's field evaluated. Mean values showed USG produced an average 17.84% of higher yield of MV rice and saved an average of 32.52% of N over prilled urea (Table 6). Usually in other areas USG performed better at lower rate of N application where as at higher rate PU and USG showed similar result in terms of grain yield (Table 7). The efficiency of nitrogen fertilizer can be increased, to some extent, by deep point placement of urea super granule (USG) and application of nitrogen with the help of leaf color chart (LCC) or SPAD meter. The use of leaf chlorophyll meter sufficiency induces 30 - 45 kg less N fertilizer use compared

Table 5. Application of SPAD (Chlorophyll meter) for need based N fertilizer management in rice cultivar PR106 grown during 1997 and 1998 at Ludhiana, India.

N management	Total N applied (kg $ha^{-1}year^{-1}$)	Mean grain yield (Mg ha^{-1})	Mean value of total N uptake (kg ha^{-1})	AE_N of 2 years Mean value (kg grain kg N $applied^{-1}$)
Zero N (control)	0	3.85	63.5	-
Recommended splits, N_{120}	120	5.3	114.5	12.25
N_{30} at SPAD < 35, N_{30} at Basal	60	4.45	83.5	9.85
N_{30} at SPAD < 35, N_{30} at Basal	30	4.45	74.5	19.6
N_{30} at SPAD < 37.5, N_{30} at Basal	90	4.45	88.5	11.9
N_{30} at SPAD < 37.5, N_{30} at Basal	90	5.6	97	19.1

$AE_{N,}$ Agronomic N use efficiency, SPAD, soil plant analysis development (chlorophyll meter reading). Source Singh et al (2002).

Table 6. Application of different sources and methods of urea fertilizer and their use efficiency

Treatments	T. Aman 2006		Boro 2007		Boro 2008	
	Grain yield (t ha^{-1})	N use efficiency (kg kg^{-1})	Grain yield (t ha^{-1})	N use efficiency	Grain yield (t ha^{-1})	N use efficiency
Control	2.80	--	2.43	--	2.8	--
[a]USG deep placement	4.51	22.8	5.13	27	6.2	34
[b]Prilled urea	4.45	22.0	4.28	14.2	6.2	34
LSD (0.05)	0.41		0.78		0.2	

[a]Prriled urea 75 kg N ha^{-1} in T. Aman and 100 kg N ha^{-1} in Boro season. Applied as 1/3 basal and broadcast 1/3 at active tillering + 1/3 at panicle initiation stage, [b]Urea Supper Granule 75 kg N ha^{-1} in T. Aman and 100 kg N ha^{-1} in Boro season. Deep placement 15 days after transplanting.

with fixed N timing treatments (Hussain et al., 2000). Nitrogen would be desirable to be applied as close as possible to the time of peak N demand by rice plant for its efficient utilization.

Phosphorus

Phosphorus (P) fertilizer needs for a crop production, depends upon its uptake and soil inherent P supplying ability. Soil P availability is positively affected by temperature and water regimes. Continuous water-logging increases P availability more at 30^0C than 20^0C. It is assumed that 6 ppm P is the critical level of soil available phosphorus (Olsen P) for lowland rice cultivation (BARC, 2005). A linear yield increase is observed from <3 to 6 ppm available P and then leveled-off up to 17 ppm (Saleque et al., 1998a). Rice had agronomic P use efficiency of 45 kg kg^{-1} and physiological P use efficiency 60 kg kg^{-1}. Application of 25 kg P ha^{-1} once in a year (Boro and T.Aman) maintained P supplying capacity of rice growing soil (BRRI, 1992). The results of BRRI farm experiment (2008) showed that in T. Aman season P response was not significant at initial 6 mg kg^{-1} soil P, while in the Boro season application of 10 kg P ha^{-1} significantly increased grain yield (Fig. 1). Wetland rice shows P recovery as high as 96% in a severe P deficient soil. In a moderate P deficient soil, BR11 rice had P recovery of 75%. Rice plant shows higher IPUE (450-650 kg kg^{-1}) at low soil available P level (3-4 mg kg^{-1}) and lower IPUE (264-330 kg kg^{-1}) at soil available P level of >9.8 mg kg^{-1} (Saleque et al., 1998a). Phosphorus should be applied during final ploughing of the field because P is an immobile nutrient in soil. Top dressing of P fertilizer at tillering stage of rice may give slight benefit in highly deficient soils only. The commonly used P fertilizers are triple super phosphate (TSP), single super phosphate (SSP) and diammonium phosphate (DAP). All the commonly used P fertilizers are 90 –100% water-soluble and dissolve rapidly when placed in moist soil. A nearly saturated solution of the P fertilizer material forms in and around fertilizer granules. While water is drawn in to the fertilizer, the fertilizer solution moves into the surrounding soils resulting in an acidic solution. Acidic solution resulting from TSP and SSP application causes other soil minerals to dissolve, increasing the cation (and anion) concentration near the granule. From 20 – 34% of the applied P will remain as this reaction product at the granule site. Although differences in pH among the various P fertilizers cause differences in reaction product chemistry, the overall effect is temporary because the volume of soil influenced by the P granule is small. In wetland rice cultivation, organic residue can be used as P fertilizer. Either cow dung or poultry manure at the rate of 1.0 ton ha^{-1} (dry weight basis) can supplement 20 kg of P ha^{-1} (from triple super phosphate, TSP). Agronomic P use efficiency is 93, 128, 66 kg kg^{-1} for TSP, cow dung and poultry manure, respectively (Saleque et al., 2009).

Potassium

Potassium (K) exists in the soil in four forms as: (1) K^+ in the solution; (2) exchangeable cation; (3) tightly held on the surfaces of clay minerals and organic matter; and (4) tightly held or fixed by weathered micaceous minerals and present in the lattice of certain K containing primary minerals (Syers, 1998). Exchangeable K^+ is the most widespread measure of available K in rice soils that account only about 1-2% of total soil K. Exchangeable K exists either in the soil solution or adsorbed on soil colloids. Critical level of exchangeable K for wetland soil appeared as 0.075 $cmol_c$ kg^{-1} (Saleque et al., 1990; Bhuiyan et al., 1992). However, Ahsan et al (1997) found rice soil can respond to applied K with low K saturation (0.19 $cmol_c$ kg^{-1}). The results of BRRI farm

Table 7. Benefit of USG over prilled urea in Barishal and Jhalokathi over the year 2003 and 2004 in Bangladesh. (Mean value of 16 experiments)

Season	Applied N (kg ha^{-1})		Grain yield (t ha^{-1})		Grain yield increase (%)		Nitrogen saving (%)	
	PU	USG	PU	USG	Season	mean	Season	mean
Aus	79	62.5	3.07	3.70	20.57		20.89	
Aman	102	62.5	3.20	3.77	17.72	17.84	38.73	32.52
Boro	141	87.5	5.07	5.84	15.23		37.94	

PU, Prilled urea USG, Urea Supper Granule, Source: Bangladesh Rice Research Institute (BRRI) Internal Review Report 2003-04.

experiments showed that in T. Aman season increasing K level up to 20 kg ha^{-1} increased grain yield of hybrid entry EH1, 40 kg K ha^{-1} BRRI dhan49 and at 80 kg K ha^{-1} BRRI dhan30. In Boro season BRRI dhan36 responded up to 60 kg K ha^{-1} (Fig. 1). Potassium should be applied during final ploughing of heavy texture soils. In light texture soils, 50% of K should be applied basal and the rest at 5 – 7 days before panicle initiation along with second split of N application. Reaction of potassium fertilizer in soil leaves no change in pH. The results of regression model combining commonly used static soil test and resin method showed that high (Ca+Mg)/K ratios may contribute to K deficiency in rice soils (Dobermann et al., 1996). Potassium fertilizer is highly soluble, thus application of the K fertilizer increases soil solution K. Long-term experiments showed that agronomic K use efficiency varied widely from year to year, being the lowest at the highest rate of application and the highest at the lowest rate of application (Abedin et al., 1997). Agronomic K use efficiency varied from 8.0-16.7 kg kg^{-1} of K fertilizer applied in Boro and 10.8-18.9 kg kg^{-1} in T.Aman season. In the same study, the recovery of applied K was found to be 27-95% in Boro season and 12-65% in T. Aman season (Saleque et al., 1998b). Bangladesh agriculture has created a negative K balance in all the AEZs (Rijpma and Jahiruddin, 2004). This may be due to the excess removal by crop and less K input through fertilizer and recycling crop residues. In rice-rice cropping pattern, avoiding K fertilizer application would result in apparent K balance of - 380 kg ha^{-1} in 5 years (Ahsan et al., 1997). This study suggested that the application of 61.34 kg ha^{-1} both for Boro and T.Aman crop along with recycling 25% of rice straw would maintain soil K reserve in rice-rice cropping pattern (Panaullah et al., 2006).

Sulfur

Basal application of sulfur (S) fertilizer is recommended; if it is not applied deficiency symptoms may appear later. S may be top dressed at any stage up to panicle initiation. The S requirement of rice varies widely. Soils that have <1.2% organic matter often requires 10 –15 kg S ha^{-1}. The common S fertilizer is gypsum, which has neutral reaction to soil. Emission of SO_2 from brickfields chimney may be a source of S for rice fields around, but it may cause soil acidity. Sterility in rice often observed in rice fields in the vicinity of brickfields.

Zinc

Zinc fertilizer is applied as basal along with other fertilizers. Zinc fertilizer requirement is very low; therefore, it may be mixed with other fertilizers. The popularly held belief that P-Zn interactions in soil, such as the formation of insoluble $Zn_3(PO_4)_2.4H_2O$, are responsible for P-induced Zn deficiency should be discontinued (Havlin et al., 2004).

Zinc sulfate ($ZnSO_4$), containing about 35% Zn, is the most common Zn fertilizer source, although use of synthetic chelates has increased. Fertilizer Zn rates depend on the crop, Zn source, method of application and severity of Zn deficiency. Rates usually range from 3 to 10 kg ha^{-1} with inorganic Zn and from 0.5 to 2.0 mg kg^{-1} with a chelate. Application of 10 kg Zn ha^{-1} in clay and loamy soils can be effective for 3 to 5 years. Root dipping of seedling in 2% ZnO suspension for 30 minutes may be recommended.

Foliar application

Foliar sprays may be excellent supplements to soil application. Foliar application is mostly suitable for micronutrients, because of their low requirement to crop plants. Nutrient concentrations of less than 1 to 2% are employed to avoid leaf injury. However, maximum concentration for P should be 0.5%, otherwise there is high possibility of leaf damage. The supplying N, P, and K in foliar sprays have difficulties in the application of adequate amounts without severely burning the leaves and without an unduly large volume of solution or number of spraying operation.

Conclusions

Balanced fertilizer application increases crop production and maintained soil fertility that is the primary requirement of sustainable agriculture. Optimum dose derived from soil plant analysis or any nutrient response studies. The rate and method of fertilizer application differed with soil physical, chemical and biological properties. An optimum dose of fertilizer application save environmental pollution and ensures farmer's profit. Practicing any fertilizer model with target yield is helpful for resource poor farmer. Efficient nutrient management for sustainable rice production guarantees minimum environmental pollution with higher crop productivity.

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References

Abedin MJ, Saleque MA, Panullah GM, Mazid MA (1998). Evaluation of two concepts of fertilization for wheat in a calcareous soil of Bangladesh. J Plant Nutr. 21:1843-1854.

Ahsan K, Saleque MA, Abedin J, Bhuiyan NI (1997). Multiple year response of wetland rice to potassium fertilizer and apparent potassium balance in soil. Thai J Agric Sci. 30:501–509.

BARC (Bangladesh Agricultural Research Council) (2005). Fertilizer recommendation guide-2005. BARC, Farmgate, New Airport Road, Dhaka 1215.

Bhuiyan NI, Saha PK, Saleque MA, Nuruzzaman M (1992). A new critical level of soil potassium for wetland rice. Bangladesh J Soil Sci. 23:1–14.

Bronson KF, Neue HU, Singh U, Abao Jr, EB (1997). Automated chamber measurements of methane and nitrous oxide flux in a flooded rice soil. I. Residue, nitrogen, and water management. Soil Sci Soc Am J. 61: 981–987.

BRRI (Bangladesh Rice Research Institute) (1992). BRRI Internal Review Report. 1991-1992.

BRRI (Bangladesh Rice Research Institute) (2000). BRRI Internal Review Report. 1999-2000.

BRRI (Bangladesh Rice Research Institute) (2003). BRRI Internal Review Report. 2002-2003.

BRRI (Bangladesh Rice Research Institute) (2004). BRRI Internal Review Report. 2003-2004.

BRRI (Bangladesh Rice Research Institute) (2008). BRRI Internal Review Report. 2007-2008.

Bruulsema T, Lemunyon J, Herz B (2009). Know your fertilizer rights. Crops Soils. 42(2): 13–18.

Dawe D, Dobermann A, Witt C, Abdulrachman S, Gines HC, Nagarajan R, Satawathananont S, Son TT, Tan PS, Wang GH (2004). Nutrient management in the rice soils of Asia and the potential of site-specific nutrient management. In: Dobermann A, Witt C, Dawe D (eds.) Increasing Productivity of Intensive Rice Systems through Site-Specific Nutrient Management, Science Publishers, Enfield, NH (USA) and International Rice Research Institute, Los Ban˜os, Philippines, p. 337–358.

De Datta SK, Buresh, RJ, Samson MI, Wang KR (1988). Nitrogen use efficiency and nitrogen-15 balances in broadcast-seeded flooded and trandplanted rice. Soil Sci Soc Am J. 52: 849-855.

Dobermann A, Witt C, Dawe D, Abdulrachman S, Gines HC, Nagarajan R, Satawathananont S, Son TT, Tan CS, Wang GH, Chien NV, Thoa VTK, Phung CV, Stalin P, Muthukrishnan P, Ravi V, Babu M, Chatuporn S, Sookthongsa J, Sun Q, Fu R, Simbahan GC, Adviento MAA (2002). Site-specific nutrient management for intensive rice cropping systems in Asia. Field Crops Res. 74: 37-66.

Dobermann A, Cassman KG, Sta Cruz PC, Adviento MA, Pampolino MF (1996). Nutr Cycl Agroecosys 46: 11-21.

Dobermann A, Fairhurst T (2000). Rice: Nutrient Management and Nutrient Disorders. PPI/PPIC and IRRI, 162 p.

Food and Agriculture Organization (FAO) (2004). Global food security and the role of sustainable fertilization. Paper presented at Agriculture Conférence, Rome, Italy, IFA-FAO, 26-28 March 2004.

Food and Agriculture Organization (FAO) (2007). Food Outlook, Global Market Analysis. Global Information and Early Warning System on food and agriculture, FAO, Rome.

Food and Agriculture Organization (FAO) (2008). Food and Agriculture Organization of the United Nations. Current world fertilizer trends and outlook to 2011/12, FAO, p57.

Furuya S (1987). Growth diagnosis of rice plants by means of leaf colour. Jpn Agric Res Quart 20:147 -154.

Havlin JL, Beaton JD, Tisdale SL, Nelson WL (1999). Soil fertility and fertilizers. Sixth Edition. Pearson Education (Singapore) Pte Ltd., Indian Branch, 482 F. I. E. Patparaganj, Delhi 110092, India.

Hussain F, Bronson KF, Yadvinder-Singh, Bijay-Singh, Peng S (2000). Use of Chlorophyll Meter Sufficiency Indices for Nitrogen Management of Irrigated Rice in Asia. Agron J. 92: 875–879.

Janicki W, Jones ARC (2004). Nutrient response to diagnostic fertilization of Norway spruce Picea aries (L.) karst plantations in Western Quebec, Canada. Water Air Soil Poll. 54: 113-118.

Janssen BH, Guiking FCT, van der Eijk D, Smaling EMA, Wolf J, Van Reuler H (1990). A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). Geoderma. 46: 299 – 318.

Li F, XunY, Li FR, Guo A (2001). Effects of different water use and yield performance of spring wheat in a simulated semi-arid environment. Agric Water Manage. 47 : 27-37.

McLean EO (1977). Contrasting concepts in soil test interpretation: Sufficiency levels of available nutrients vs. basic cation saturation ratios. In: ASA, Special Publication No. 29, Soil testing: Correlation and interpreting the analytical results, ASA, Special Publication, p 39-54.

Mengel K (1982). Factors of plant nutrition relevant to soil testing. Plant Soil. 64: 129-138.

Panaullah GM, Timsina J, Saleque MA, Ishaque M, Pathan ABMBU, Connor DJ, Humphreys E, Saha PK, Quayyum MA, Meisner CA (2006). Nutrient concentrations, uptake and apparent balances for rice-wheat sequences. III. Potassium. J Plant Nutr. 29: 173-187.

Pampolino MF, Manguiat IJ, Ramanathan S, Gines HC, Tan PS, Chi TTN, Rajendran R, Buresh RJ (2007). Environmental impact and economic benefits of site-specific nutrient management (SSNM) in irrigated rice systems. Agri Syst. 93: 1–24.

Rijpma J, Jahiruddin M (2004). Final report on national strategy and plan for use of soil nutrient balance in Bangladesh. Soil Fertility and Fertilizer Management Project consultancy report, DAE, Khamarbari, Dhaka.

Saleque MA, Saha PK, Panaullah GM, Bhuiyan NI (1990). Calibration of soil potassium tests with yield of wet season lowland rice in Bangladesh. Bangladesh J Soil Sci. 21: 1–10.

Saleque MA, Abedin MJ, Panaullah GM, Bhuiyan NI (1998a). Yield and phosphorus efficiency of some lowland rice varieties at different levels of soil available phosphorus. Commun Soil Sci Plant Anal 29: 2905–2916.

Saleque MA, Saha PK, Panaullah GM, Bhuiyan NI (1998b). Response of wetland rice to potassium in farmers' fields of the Barind tract of Bangladesh. J Plant Nutri. 21: 39–47.

Saleque MA, Anisuzzaman M, Moslehuddin AZM (2009). Quantity-intensity relationships and potassium buffering capacity of four Ganges river floodplain soils. Commun Soil Sci Plant Anal. 40: 1333 - 1349.

Schnier HF (1994). Nitrogen-15 recovery fraction in flooded tropical rice as affected by added nitrogen interaction. Eur J Agron. 3: 161–167.

Shen S (2002). Contribution of nitrogen fertilizer to the development of agriculture an dits loss in China. Acta Pedol Sin. 39: 12-25.

Singh B, Singh Y, Ladha JK, Bronson KF, Balasubramanian V, Singh J, Khind CS (2002). Chlorophyll Meter– and Leaf Color Chart–Based Nitrogen Management for Rice and Wheat in Northwestern India. Agron J. 94: 821–829.

Syers JK (1998). Soil and Plant Potassium in Agriculture. Paper Presented at Fertiliser Society in a Meeting in London on 30 April 1998 (Proceedings No. 411), The Fertiliser Society, New York, p 32.

Trolldenier G (1977). Mineral nutrition and reduction process in the rhizosphere in rice. Plant Soil. 47: 193-202.

Witt C, Buresh RJ, Peng S, Balasubramanian V, Dobermann A (2007). Nutrient management. In: Fairhurst TH, Witt C, Buresh R, Dobermann A, (eds) Rice: A practical guide to nutrient management. Los Baños (Philippines) and Singapore: International Rice Research Institute (IRRI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI), p 1-45.