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Targeted yield concept and a framework of fertilizer recommendation in irrigated rice domains of subtropical India*

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Abstract: Soil test crop response (STCR) correlation studies were carried out in Vindhyan alluvial plain during 2001 to 2004 taking IR-36 as test crop to quantify rice production in the context of the variability of soil properties and use of balanced fertilizers based on targeted yield concept. The soils were developed on gently sloping alluvial plain with different physiographic settings and notable variation in drainage condition. Soil properties show moderate variation in texture (loamy to clay), organic carbon content (4.4 to 9.8 g/kg), cation exchange capacity (10.2 to 22.4 cmol (p+)/kg) and pH (5.3 to 6.4). Soil fertility status for N is low to medium (224 to 348 kg/ha), P is medium to high (87 to 320 kg/ha) and K ranges from medium to high (158 to 678 kg/ha). Database regarding nutrient requirement in kg/t of grain produce (NR), the percent contribution from the soil available nutrients [CS (%)] and the percent contribution from the applied fertilizer nutrients [CF (%)] were computed for calibrating and formulating fertilizer recommendations. Validity of the yield target for 7 and 8 t/ha was tested in farmers' fields and yields targets varied at less than 10%. The percent achievement of targets aimed at different level was more than 90%, indicating soil test based fertilizer recommendation approach was economically viable within the agro-ecological zone with relatively uniform cropping practices and socio-economic conditions.

Key words: Alluvial soil, Nutrient requirements, Yield target, Paddy
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INTRODUCTION

Damodar catchment is one of the most potential zones for paddy cultivation in India. Paddy is being cultivated about 80% area during monsoon season and about 60% area during winter season. To get more and more yield farmers inclined to the excess use of chemical fertilizers, but the decision on fertilizer use requires knowledge of the expected crop yield response to nutrient application, which is a function of crop nutrient needs, supply of nutrients from indigenous sources, and the short- and long-term fate of the fertilizer applied (Dobermann *et al*., 2003a). Dumping of fertilizers by the farmers in the fields without information on soil fertility status and nutrient requirement by crop causes adverse effects on soil an crop regarding both nutrient toxicity and deficiency either by overuse or inadequate use (Ray *et al*., 2000). Managing the location specific variability in nutrient supply is a key strategy to overcome the current mismatch of fertilizer rates and crop nutrient demand in irrigated rice environments (Dobermann and Cassman, 2002).

Soil test based application of plant nutrient helps to realize higher response ratio and benefit:cost ratio as the nutrients are applied in proportion to the magnitude of the deficiency of a particular nutrient and the correction of the nutrients imbalance in soil helps

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to harness the synergistic effects of balanced fertilization (Rao and Srivastava, 2000). Location specific fertilizer recommendations are possible for soils of varying fertility, resource conditions of farmers and levels of targeted yield for similar soil classes and environment (Ahmed *et al*., 2002). Field specific balanced amounts of N, P, K were prescribed based on crop based estimates of the indigenous supply of N, P and K and by modelling the expected yield response as a function of nutrient interaction was done by many workers (Dobermann and White 1998; Witt *et al*., 1999).

The present investigation aimed to study the relationship between the nutrient supplied by the soil and added fertilizers, their uptake and yield of paddy and to develop a guideline for judicious application of fertilizer for maximum production of paddy.

MATERIALS AND METHODS

The study was conducted in three villages viz. Naopara, Kantia and Syamsundarpur in Barddhaman district, West Bengal, India for the year 2001 to 2004. Crop trials were conducted in four soil series viz. Syamsundarpur I, Syamsundarpur II, Naopara and Kantia, in the farmer's field. Irrigated rice (IR-36) was also used as the winter crop in the third week of February and harvested in the third week of May. The crop was transplanted at a spacing of 14 cm×12 cm with 5 seedlings/hill. The crop received one fourth N and full dose of P_2O_5 and K_2O as basal application and remaining half and one fourth N were applied at 22 d after transplanting (DAT) and 45 DAT respectively. Nitrogen was applied through urea, phosphorus through diammonium phosphate (DAP) and potassium through muriate of potash. Five to seven centimeters deep good quality water was maintained in the field. All the plots were weeded thrice, once before first top dressing and again before second top dressing and last weeding 11 d after second weeding. Panicles were counted from 4 random locations in each plot and for filled grains/panicle, 20 panicles of each plot were separated and then average filled grains/panicle were calculated, whereas weight of 1000 filled grains was taken as test weight.

Fifty-six soil samples (0~0.15 m depth) were collected, dried and passed through 2 mm sieve and analyzed for physicochemical characteristics as described by Jackson (1973). Available nitrogen was analyzed by alkaline permanganate method (Subbaiah and Asija, 1956), available phosphorus by Olsen *et al*.(1954)'s method and available potassium by ammonium acetate method (Hanway and Heidal, 1952). The layout was based on the approach developed by Ramamoorthy *et al*.(1967). Four levels of fertilizer treatment viz. $N_1P_1K_1$ (farmers practice), $N_2P_2K_2$ (soil test based i.e. recommended by the agricultural department of the district on the basis of soil test values), $N_3P_3K_3$ [soil test crop response (STCR) for 7 t/ha] and $N_4P_4K_4$ (STCR for 8 t/ha) with three replications each was done. Pre-sowing and post-harvest soil samples were analyzed according to the standard procedures. Plant sampling was done according to the procedure followed by Witt *et al*.(1999). In targeted yield approach for formulating fertilizer recommendations, the basic data viz. nutrient requirement (NR) (kg/t), percent contribution from the soil available nutrients [CS (%)] and the percent contribution from the applied fertilizer nutrients [CF (%)] were transfer into workable adjustment equation (Rao and Srivastava, 2000).

$$\text{Fertilizer dose}=[\text{Nutrient requirement (kg/t) of grain}]/[\text{CF (\%)}]\times 100\times T\ \text{(t/ha)}-[\text{CS (\%)}]/[\text{CF (\%)}]\times[\text{Soil test value (kg/ha)}],$$

where T is targeted yield (t/ha).

RESULTS AND DISCUSSION

Crop trials were done with the basic assumption that fertilizer recommendations typically depend on crop response experiments in which spatial variability has been minimized for every independent variable affecting crop yield except for the nutrient in question, although many non-fertility variables viz. soil texture, soil bulk density, available water content and other fertility variables significantly impact crop yield (Kastens *et al*., 2003).

Soil characteristics

The soils were acidic to neutral in reaction with pH varying from 5.3 to 6.4 (Table 1). The organic carbon content varied from 0.44% to 0.98%. Texture

Table 1 Soil resource inventory of the study area

Soils	Description of soils (DS)*	Physicochemical properties						Fertility status (kg/ha)		
		pH (H_2O)	Org. C (%)	Clay (%)	*CEC* [cmol (p^+)/kg]	*BS* (%)	*AWC* (kg/kg)	N	P_2O_5	K_2O
Syamsundarpur I series (Typic Haplustepts)	DS1	6.4	0.44	18.5	10.2	79	0.144	241~269	256~276	158~169
Syamsundarpur II series (Aeric Endoaquepts)	DS2	6.0	0.98	36.9	18.5	79	0.166	265~327	87~113	517~565
Naopara series (Aeric Endoaquepts)	DS3	5.3	0.98	34.9	14.6	72	0.160	245~348	248~320	365~678
Kantia series (Typic Endoaquepts)	DS4	6.0	0.73	57.4	22.4	79	0.189	224~285	115~185	205~272

*DS1: Deep, moderately well drained, fine loamy soils developed on upland with loam surface texture and moderate erosion; DS2: Deep, imperfectly drained, fine soils developed on midland with silty clay loam surface texture and slight erosion; DS3: Deep, moderately well drained, fine soils developed on midland with silty clay surface texture and slight erosion; DS4: Deep, poorly drained, fine soils developed on lowland with clay surface texture and slight erosion. Org. C: Organic carbon; CEC: Cation exchange capacity; BS: Base saturation; AWC: Available water capacity

of the surface soil varied from loam to clay with clay percent varying from 18.5% to 57.4%. CEC (cation exchange capacity) of the soils were medium with high base saturation. Field capacity and plant available water holding capacity values showed that the soils were highly capable of containing soil moisture. The soils were low to medium in N (ranging from 224 to 348 kg/ha), medium to high in P (ranging from 87 to 320 kg/ha) and medium to high in K (from 158 to 678 kg/ha). Available micronutrient status showed that the experimental soils were well supplemented with micronutrients. Though these soils are considered to be most fertile, they are deficient in nitrogen and humus but moderately supplied with phosphorus and potassium.

Yield targeting of paddy based on soil test

Experimental data on follow up tail as frontline demonstration, 13 for each soil series during the period 2001~2003 were conducted in farmers field and are given in Tables 2 and 3. From the field experiment the basic data on nutrient requirements (NR) to produce one quintal of rice, percent contribution of nutrients from soil [CS (%)] and fertilizer [CF (%)] were evaluated. Indigenous sources in an irrigated system include plant available nutrients derived from chemical and biological transformations of soil solids, biological N_2 fixation in the floodwater-soil system, atmospheric deposition and solutes and sediments deposited by irrigation (Cassman *et al*., 1998). Nutrient requirement per ton of rice production were

Table 2 Basic data and fertilizer adjustment equations of paddy (IR-36) in alluvial soils of Barddhaman, West Bengal

Nutrient	Basic data			Targeted yield equations
	NR (kg/t)	*CS* (%)	*CF* (%)	
N	14.8	13.56	67.64	$F_N=2.19T-0.2S_N$
P_2O_5	10.5	31.59	84.67	$F_P=1.24T-0.37S_P$
K_2O	18.6	19.33	139.89	$F_K=1.33T-0.14S_K$

NR: Nutrient requirement (kg/t) of grain production; CS (%): Percent nutrient contributed from soil (soil efficiency); CF (%): Percent nutrient contributed from fertilizer (fertilizer efficiency); *T*: Yield target (t/ha); S_N, S_P and S_K: Soil available nitrogen, phosphorus and potassium (kg/ha); F_N, F_P and F_K: Fertilizer nitrogen, phosphorus (P_2O_5) and potassium (K_2O) required (kg/ha)

observed to be 14.8, 10.5 and 18.6 kg N, P_2O_5 and K_2O respectively. Contribution of N, P_2O_5 and K_2O as estimated from soil and fertilizer sources was 13.56%, 31.59%, 19.33% and 67.64%, 84.67%, 139.89% respectively. These results indicate that nutrient contribution from fertilizer sources was greater than that from the soil source. The findings are in closely accorded with those reported by Ray *et al*.(2000) and Meena *et al*.(2001). It is interestingly noted that contribution of K_2O for rice (Table 2) was observed to be more than 100% (139.89%). This high value of K could be due to the interaction effect of higher doses of N, P and the primary effect of starter K doses in the treated plots, which might have caused the release of soil potassium form, resulting in the higher uptake from the native soil sources by the crop (Ray *et al*., 2000). Similar type of higher efficiency potassic

Table 3 Field verification trails of fertilizer adjustment equations of paddy in inceptisols of Barddhaman

Soil series (farmer)	Soil test values (kg/ha)			Treatments	Fertilizer doses (kg/ha)			Yield (t/ha)	Increased over control (t/ha)	Yield deviation (%)	*B*:*C* ratio
	N	P_2O_5	K_2O		N	P_2O_5	K_2O				
Syamsundarpur I	245	70	162	FP	100	80	40	6.002	3.512	−	1.54
(T. Dutta)				GRD	120	50	50	6.150	3.660	−	1.61
				7 t/ha target	104	61	70	6.669	4.179	−4.73	1.72
				8 t/ha target	126	73	84	7.225	4.735	−9.69	1.81
				Control	0	0	0	2.490	−	−	−
Syamsundarpur II	272	80	340	FP	100	80	40	6.113	3.573	−	1.56
(N. Bhattacharjee)				GRD	120	50	40	6.224	3.684	−	1.62
				7 t/ha target	100	57	46	6.817	4.277	−2.61	1.75
				8 t/ha target	121	70	59	7.558	5.018	−5.53	1.89
				Control	0	0	0	2.460	−	−	−
Naopara	345	110	385	FP	100	80	40	6.224	3.584	−	1.59
(S. Ghosh)				GRD	100	40	40	6.373	3.733	−	1.66
				7 t/ha target	84	46	40	6.817	4.177	−2.61	1.75
				8 t/ha target	106	59	53	7.632	4.992	−4.60	1.89
				Control	0	0	0	2.640	−	−	−
Kantia	275	90	220	FP	100	80	40	6.113	3.503	−	1.56
(N. Mondal)				GRD	120	40	50	6.298	3.688	−	1.64
				7 t/ha target	100	54	62	6.854	4.244	−2.10	1.76
				8 t/ha target	120	66	76	7.595	4.985	−5.10	1.89
				Control	0	0	0	2.610	−	−	−

A minor modification was made in the ready reckoner; FP : Farmers practice i.e. the fertilizer doses the farmers generally applied in the area; GRD: General recommendation by the agricultural department of the district on the basis of soil test values; *B*:*C* ratio: Benefit:cost ratios

fertilizer was also reported for rice by Ahmed *et al*.(2002) in alluvial soil, for maize by Reddy *et al*.(2000) in inceptisols and for jute by Ray *et al*.(2000) in inceptisols.

Yield target of 7.0 t/ha has been achieved with comparatively lower application of N and P_2O_5 fertilizers but higher application of K_2O, in comparison to doses applied in farmers practice (FP) and soil based recommendations. As for example in the alluvial soils of West Bengal, in the winter season highest paddy yield was 6.0 t/ha regardless of the N level used but could be raised to 7.4 t/ha with increased application of K-fertilizers (Tiwari, 2002). This is probably due to the higher N-use efficiency as well as increased N-recovery by crops under increased K-application (Marschner, 1995).

Yield targets of 7 and 8 t/ha for rice (cv. IR-36) were achieved within –10% yield deviation (Table 3) from the expected yield targets in all the cases. In all sites, grain yields of rice through general recommendation (GRD) of fertilizers lagged behind the yield obtained at 7 and 8 t/ha fixed target. These results accorded with the findings of Ray *et al*.(2000). Between the two targets tried, targeting for 7 t/ha recorded relatively higher response ratio than with 8 t/ha though it has also recorded higher yields. This might be due to the better use efficiency of applied NPK fertilizers at low yield target levels (Santhi *et al*., 2002).

However for efficient utilization of applied fertilizer some other parameters like soil pH, organic carbon status, soil texture, bulk density, water holding capacity, soil drainage, etc. should also be considered, since these are the major determining factors of soil nutrient retention. This is for the development of an effective fertilizer schedule as well as nutrient supply source in view of the better nutrient absorption and assimilation by the plants.

Predicting equation for post-harvest soil test values

Using a soil test based approach to nutrient management requires index measurement related to crop yield or the effective nutrient supply during the growth period, regular monitoring of soil test values and well developed service infrastructure with excellent quality control (Dobermann *et al*., 2003b) which is not feasible in farmers point of view. So it has become necessary to predict the soil test values after the harvest of a crop. It is done by post-harvest soil test value predicting equations making use of the vital soil test values, applied fertilizer doses and the obtained nutrients uptake. The functional relationship is as follows

$$Y_{ph}=a+b_1\times F+b_2\times IS+b_3\times \text{Yield/(Uptake of nutrient)},$$

where Y_{ph} is the post-harvest soil test value, F is the applied fertilizer nutrient and IS is the initial soil test value, a is an absolute constant and b_1, b_2 and b_3 are the respective regression coefficients.

The predicting equations are highly significant for the major nutrient viz. N, P_2O_5 and K_2O in the study area (Table 4). The soil test values generated through this predicting equation may be utilized for soil test based fertilizer recommendation for the next crop in the crop rotation.

Table 4 Predicting equations for post-harvest soil test values for paddy (IR-36)

Nutrient	R^2	Multiple regression equation
N	0.93^{**}	$Y_N=-22.70+1.0S_N+0.15F_N-0.56RY$
P_2O_5	0.94^{**}	$Y_P=-1.70+0.64S_P+0.41F_P-0.29RY$
K_2O	0.99^{**}	$Y_K=24.80+0.93S_K+087F_K-2.29RY$

S_N, S_P and S_K: Soil available nitrogen, phosphorus (P_2O_5) and potassium (K_2O) (kg/ha); F_N, F_P and F_K: Fertilizer nitrogen, phosphorus (P_2O_5) and potassium (K_2O) required (kg/ha); RY is rice yield (kg/ha); **Significant at 1% level

CONCLUSION

Nutrient management for rice should focus on developing fertilizer recommendations for spatial domains with relatively uniform agro-ecological characteristics, cropping practices and socio-economic conditions. The study will help to make guidelines for the amount of fertilizer used in rice cultivation. With the variation in conditions like different cultivars, soil conditions, etc. fertilizer requirement will change. However the change will not be significant for cultivars of similar producing capacity. Now with the variation of soil and climate, the contribution from soil varies since the nutrient releasing capacity of soil depends upon its different properties, which are indicated in the assumption. Now, Barddhaman is a representative site of the widely spread Ganga-Brahmaputra alluvial plain with similar climatic conditions, where this experiment can be applied as a pilot study for the whole area under consideration.

The specific yield equation based on soil health will not only ensure sustainable crop production but will also steer the farmers towards economic use of costly fertilizer inputs depending on their financial status and prevailing market price of the crop under consideration.

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