A Site-Specific Fertilizer Recommendation for Rice Grown in Imperfectly Drained Reddish Brown Earth Soils in Low Country Dry Zone of Sri Lanka

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***ABSTRACT**. Imbalanced and low availability of some nutrients are the major limitations to realize the potential yield of rice in Elayapattuwa soil series that comes under Reddish Brown Earth great soil group in the Low Country Dry Zone of Sri Lanka. A site-specific nutrient recommendation based on initial soil analysis and sorption studies for K, P, S, Zn, B, Cu and Mn and a greenhouse nutrient survey with optimum treatment was formulated. This was field tested along with few other treatments with slightly different combinations of N, P, K, Mg, S, and Zn, and compared with the optimum treatment and the present Department of Agriculture (DOA) recommendation. Results showed that a considerable amount (~18%) of added P was fixed in this soil while K, S, B, Cu and Zn fixation were below 12% of added amounts. The highest dry matter yield in the greenhouse study was given by the optimum (Opt) treatment. In treatments where a nutrient was omitted from the Opt treatment, respective deficiency symptoms appeared with low biomass yields. Field experiments conducted for two consecutive seasons confirmed that nutrient rates provided by the Opt treatment computed using the site-specific approach amounting to; 175 kg N, 60 kg P, 120kg K, 25kg Mg, 50 kg S and 2 kg Zn per hectare, gave significantly higher rice yields than the other treatments including the present DOA fertilizer recommendation. However, the treatment with 175 kg N, 35 kg P, 60 kg K, 15 kg Mg, 25 kg S and 2 kg Zn, which contains lower amounts of P, K, Mg and S than the Opt treatment, gave grain yields similar to that of the Opt treatment.*

INTRODUCTION

Recent research conducted in the world has demonstrated the limitations of currently used blanket fertilizer recommendations for large rice growing areas. Various on-farm studies suggested large, but potentially manageable variability in soil nutrients among rice farms or small rice fields (Adhikari *et al*., 1999; Angus and Tacic, 1990; Cassman *et al*., 1996; Doberman and Oberthir, 1997; Wopereis *et al.,* 1999). Research with N, P and K nutrients have revealed that the nutrient imbalances may limit the yield of rice and that the existing soil test methods had limited applicability to lowland rice (Doberman *et al.,* 1996). Rice crop management over the past 4 decades in Sri Lanka was driven by the increasing use

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of external inputs and blanket recommendation for fertilizer use over wide areas. However, future gains in productivity and input use efficiency will require soil and crop management technologies that are more knowledge intensive and pertaining to the specific characteristic of individual farms and fields. Recent on-farm research has demonstrated that large variability exists in soil nutrient supply, nutrient use efficiency and crop response to nutrients among rice farms or single rice fields (Adhikari *et al.,* 1999, Dobermann *et al*., 1996, Wickramasinghe and Wijewardana, 2000, Bandara *et al.,* 2003, 2004). Managing this variability has become a principal challenge for further increasing the productivity of these intensive rice areas.

Elayapattuwa soil series *(Haplustalfs)*, which comes under imperfectly to poorly drained Reddish Brown Earth great soil group in the Low Country Dry Zone is widely used for rice cultivation and contributes 10% of the total rice production in Sri Lanka. Deficiency of nutrients and depletion of organic matter are the main limitations in this soil series (Wickramasinghe, 2006). Ninety eight percent of rice growing area of this soil series is cultivated with new improved rice varieties, which require balance fertilization to obtain the maximum yield (Wickramasinghe and Wijewardana, 2000; Wickramasinghe, 2006). However, use of high yielding rice varieties and intense cropping has contributed towards the speedy removal of major, secondary and micronutrients from soils (Fairhurst and Dorbermann, 2002). Of essential nutrients, N, P and K are required in large proportions and also the most limiting nutrients in this soil. Secondary and micronutrients deficiency may be one of the other reasons for lower yield (Bandara and Silva, 2000; Deb, 1992).

Nutrient imbalances produce low yields, low fertilizer use efficiency (Bandara and Silva, 2001) and low farmer profit (Fairhurst and Dorbermann, 2002). It also results in further depletion of the most deficient nutrients in the soil. Hence, balanced fertilization is important in increasing crop yields. Conventional or present standard procedures for recommending nutrient application to rice crop are soil analysis, field experiments and subsequently considering response of each nutrient on growth and yield. Sometime this method gives erratic results. Adsorption capacity of soils is important for nutrients like P, K, S and micronutrients like B, Cu, Mn, Zn as the amount of fertilizer needed to bring the soil solution nutrient level up to the critical level depends on the adsorption capacity (Hunter, 1984). In standard soil analysis for nutrients recommendation, adsorption capacity, which varies among soils, is not considered.

A systematic approach for balanced fertilizer recommendations for crops has been developed on the basis of soil test, fixation study, greenhouse, and field experiments (Portch and Hunter, 2002; Dowdle and Portch, 1988). This approach involves soil sampling, chemical analysis, nutrient adsorption study, and greenhouse and field experiments. Using this methodology, many soils sampled from different Agro Ecological Regions (AER) in Sri Lanka were found to be deficient in macro as well as micro nutrients (Kumaragamage and Indraratne, 2002). This technique has been successfully used to diagnose soil problems and recommend appropriate fertilizers (Hunter, 1984; Portch, 1988). Therefore, this study was conducted to develop and test a site specific fertilizer recommendation for rice grown in *Elayapattuwa* soil series *(Haplustalfs)* that comes under the Reddish Brown Earth great soil group in the Low Country Dry Zone (LCDZ) of Sri Lanka to increase the grain yield of rice.

MATERIALS AND METHODS

Experimental site containing *Elayapattuwa* soil series *(Haplustalfs)* was located at MahaIlluppallama seed farm in the DL1b AER. Approximately, a 50 kg composite soil sample was collected from the plough layer of the rice field and air-dried. A sub sample was passed through 2 mm mesh screen and used for laboratory analysis.

Routine soil analysis

Soil pH, organic matter % (OM) and cation exchange capacity were determined using standard procedures (Portch and Hunter, 2002). Available nutrients in the soil were determined using a 3-step extraction procedure proposed by Portch and Hunter (2002), using 0.25M $NaHCO_3$ + 0.01M EDTA + 0.01M NH_4F extractant for P, K, Cu, Fe, Mn, Zn (extraction 1), 0.08M calcium phosphate ($Ca(H_2PO_4)_2.H_2O$) extractant for S, B (extraction 2) and 1M KCl extractant for NH_4-N, Ca, Mg, Na and active acidity (extraction 3).

Phosphorus content in the extract 1 was determined by phospho-molybdate blue method at 680 nm using a spectrophotometer (Shimadzu -1601). Concentrations of K, Cu, Fe, Mn and Zn in the extract 1 were determined using an atomic absorption spectrophotometer (GBC-932 AA). Sulfur concentration in the extract 2 was determined by the turbidimetric method (Portch and Hunter, 2002) while B was determined by the colorimetric method after treating with curcumin using a spectrophotometer at 555nm (Portch and Hunter, 2002). A 10 ml aliquot of the extract 3 was titrated with 0.01M NaOH using phenolphthalein indicators to determine the active acidity (Portch and Hunter, 2002). Ammonium-N was determined by using the indophenol blue colorimetric method at a wavelength of 630 nm using a spectrophotometer (Shimadzu -1601). Concentrations of Ca, Mg and Na in extract 3 were determined by atomic absorption spectrophotometer (GBC-932 AA).

Adsorption/Fixation study

The fixation studies were carried out by adding a specific quantity of element in a solution to a specific weight of soil and subsequent extraction of the soil. One set of treatments containing P, K, Cu, Mn and Zn and another set of treatments containing S and B were prepared. In the first set of treatments, 6 levels of each nutrient at the rate of 0, 25, 51, 102, 203 and 407 mg K/kg soil; 0, 20, 40, 80, 160, 320 mg P/kg soil; 0, 1, 2, 4, 8, and 16 mg Cu/kg soil; 0, 5, 10, 20, 40, and 80 mg Mn/kg soil and 0, 2.5, 5, 10, 20 and 40 mg Zn/kg soil were used. In the second set of treatment 0, 10, 20, 40, 80 and 160 mg S/kg soil and 0, 0.25, 0.5, 1, 2, and 4 mg B/kg soil were used (Portch and Hunter, 2002). Six samples of 2.5 g of soil were supersaturated with 2.5 ml of the first set of solutions, and allowed to incubate for 3 days and air dried. Samples were extracted and analyzed using the same procedure as for the elements in the original routine analysis of the soil (Portch and Hunter, 2002).

Six samples of 5 g soil were treated with 5 ml of the second set of fixation solution, followed by the same procedure as given above, air dried and extracted with 25 ml of 0.08M $Ca(H_2PO_4)_2.H_2O$ to determine available S and B. The measured or extracted amounts of the elements were plotted against the added amounts. The extracted amounts correspond to the amount extracted from original soil plus the added amount that was not adsorbed on to the soil.

Using data from initial soil analysis, the fixation studies and the established critical and optimum levels (Dobermann and Fairhurst, 2000; Portch and Hunter, 2002), fertilizer requirements to maintain optimum level of each element in soil to realize high yields were calculated.

Greenhouse pot experiment

A pot experiment was conducted in the greenhouse using rice variety Bg 352 at the Rice Research and Development Institute, Batalagoda. The experiment included 13 treatments (optimum treatment, -N, -P, -K, -Mg, -S, -Zn, -Mo, +Mn, +Cu, +B, +Fe, No Fertilizer) with 4 replicates arranged in completely randomized design for the same soil. The optimum (Opt) treatment was formulated based on the results of the initial soil test, adsorption study and optimum level of each nutrient (Dobermann and Fairhurst, 2000; Portch and Hunter, 2002) to be in the soil, which supplemented all the necessary nutrients considered to be deficient or inadequate for healthy growth of the crop, at adequate levels. To the Opt treatment, N, P, K, S, Zn and Mo were included (as they were deficient in soils) and B, Cu, Mn, Fe, were excluded (as they were sufficient). Magnesium was also added to the Opt treatment as it was required to maintain the Mg:K at optimum level in the soil (Portch and Hunter, 2002). To each of the minus treatments, the individual element was not added, in order to examine the effect of not supplying a particular nutrient on plant growth. In plus treatments, each sufficient nutrient was added, to examine the effect of supplying these nutrients on plant growth even though soil analysis indicated adequate levels of these nutrients. Each treatment was added to 300 g soil in plastic pots and allowed to stand for 2 days. Ten germinated rice seeds (variety Bg 352) were sown after saturating the soils with de-ionized water and water level was maintained to 1-2 mm from the soil surface until harvest. After 6 weeks, rice shoots were harvested and oven dried. The relative dry matter yield in each treatment was calculated considering the dry matter yield of the treatment in relation to the yield of the Opt treatment.

Field experiment

A field experiment was established in a selected field at the MahaIlluppallama seed farm in the LCDZ. Treatments tested (Table 1) were arranged in a randomized complete block design with 3 replicates in 2004 *Yala* season. Eighteen day old rice seedlings of variety Bg 352 were transplanted at 15 cm x 15 cm apart in 6 m x 3 m plots surrounded by 0.3 m bunds. All other management practices were as recommended by the Department of Agriculture. Soil samples were taken from each plot at the maximum tillering and were analyzed for nutrient contents using the 3-step extraction procedure (Portch and Hunter, 2002). Plant samples were also taken and analyzed for nutrients. Rice crop was harvested and grain yield was recorded. The experiment was repeated in the same plots with the same treatments in 2004/05 *Maha* season.

Statistical Analysis

Results of greenhouse and field experiments were statistically analyzed for analysis of variance (ANOVA) using the GLM procedure using Statistical Analysis Software (SAS, 1988) and mean comparisons were done using Duncan Multiple Range Test at 5% probability level.

Table 1. **Rates of nutrient (kg/ha) applied in different treatments in the field experiment.**

Treat.	Criteria	Nutrient rate (kg/ha)					
		N	P	K	S	Mg	Zn
T_1	Opt	175	65	120	50	25	2
T_2	N_1	150	65	120	50	25	2
T_3	P_0	175	0	120	50	25	2
T_4	P_1	175	35	120	50	25	2
T_5	K_0	175	65	0	50	25	2
T_6	K_1	175	65	60	50	25	2
T_7	Mg_1	175	65	120	50	15	2
T_8	Mg_0	175	65	120	50	0	2
T_9	S_1	175	65	120	25	25	2
T_{10}	S_0	175	65	120	0	25	2
T_{11}	Zn_0	175	65	120	50	25	0
T_{12}	DOA	140	22	42	0	0	1
T_{13}	No fert.	0	0	0	0	0	0

Note: DOA - Department of Agriculture.

RESULTS AND DISCUSSION

Soil properties

The soil tested was low in OM content (1.8%), slightly acidic (pH) and deficient in available N. Contents of P, K, S and Zn, were close to critical or deficient levels, while Mg, B, Cu and Mn were at sufficient levels (Table 2). Available Fe content was excessive. Cation exchange capacity was low, but Ca:Mg was in an acceptable range (Table 2). However, Mg:K had to be adjusted to the range between 1.1-4.5 by adding Mg and K fertilizers as described by Portch and Hunter (2002). As such, this soil was medium fertile for the rice crop and should be amended with required plant nutrients to achieve higher yield as reported earlier by Wickramasinghe (2006).

Absorption isotherms based on fixation studies

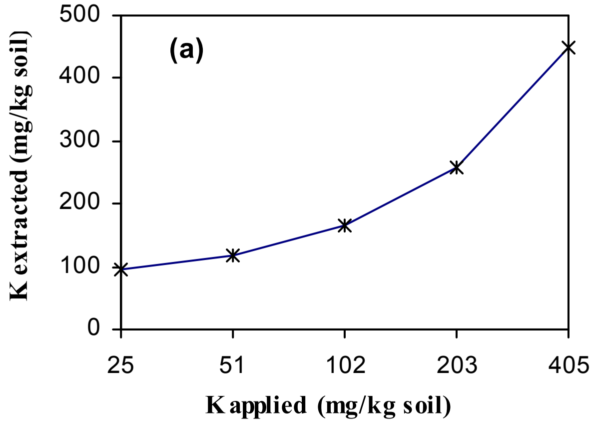
Potassium fixation was low in this soils and only about 7-9% of added K was fixed (Fig. 1a). Comparatively fixation of P and S was higher (7-18% and 4-13%, respectively), at high levels of added nutrients (Figs 1b and c). Fixations of Zn, B, and Cu were 12, 4-12 and 4-8%, respectively (Figs 2a, b, and c). Fixation of Mn was very low and almost all the added and soil Mn was recovered (Fig. 2d). This may be due to increased availability of Mn under reduced conditions (Ponnamperuma, 1977).

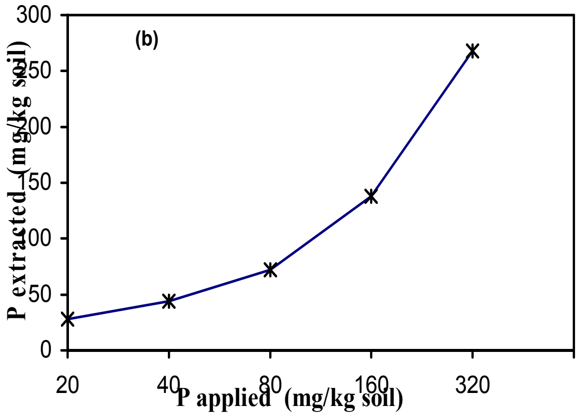
Nitrogen and Magnesium fertilizer requirements to this crop were calculated considering initial soil analysis and 100 mg N/kg and 1.3 of Mg:K as optimum levels in soil. Optimum levels of K, P, S and Zn fertilizers were determined using fixation curves (Figs 1 and 2a). B, Cu, and Mn fertilizers were not added as they were found in sufficient levels (Table 2 and Fig. 2).

Table 2. Initial soil chemical properties of Elayapattuwa soil series and nutrient rates for optimum treatment in the field experiment.

Soil property	Initial value	Soil conditions in terms of each soil property		Amounts to be added to adjust to optimum level	
		Critical level	Optimum range	mg/kg	kg/ha
pH (1:5 soil: water)	6.5	-	6.2-7.2	-	-
OM (%)	1.8	>3	3-5	-	-
CEC (cmol(+)/kg soil)	6.2	>5	15-20	-	-
A.acidity (c mol(+)/kg soil)	0.1	-	-	-	-
Ca (mg/kg)	840	520	700	-	-
Mg (mg/kg)	142	96	120-182	12.5	25.0
K (mg/kg)	78	78	117-156	60.0	120.0
Ca:Mg	3.8	3.4	3.9-11.9	-	-
Mg:K	5.5	0.9	1.1-4.5	-	-
N (mg/kg)	12.5	-	100	87.5	175.0
P (mg/kg)	10.5	12	24-48	32.5	65.0
S (mg/kg)	20	12	24-40	25.0	50.0
B (mg/kg)	0.8	0.4	0.8	0.0	0.0
Cu (mg/kg)	2.6	1.0	2-3	0.0	0.0
Fe (mg/kg)	72	5	12-24	0.0	0.0
Mn (mg/kg)	28	4.0	12	0.0	0.0
Zinc (mg/kg)	0.8	1.5	2-4	1.0	2.0

Note: Critical levels and optimum ranges adapted from nutrient disorders and nutrient management in rice by Dobermann and Fairhurst (2000) and Portch and Hunter (2002);
*Analytical methods based on Portch and Hunter (2002).





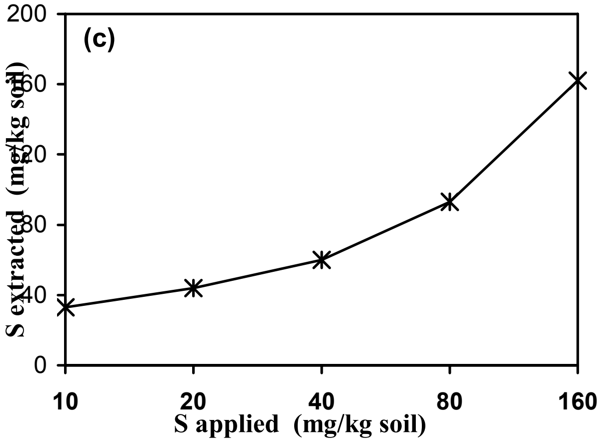


Fig. 1. Fexation curves for Elayapattuwa Soil Series, K (a), P (b) and S (c).

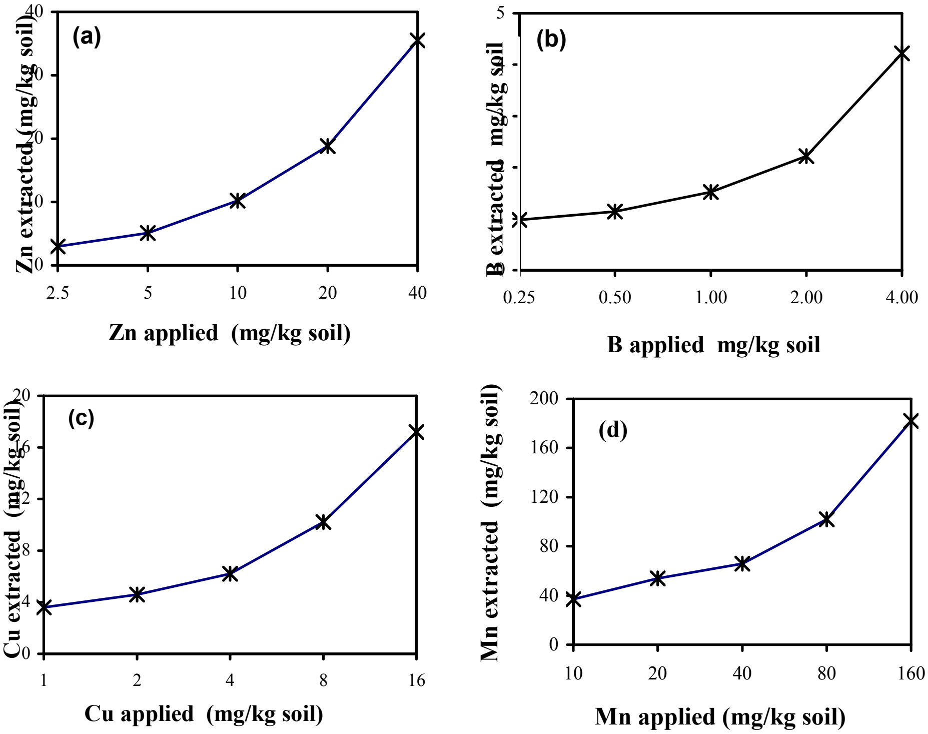


Fig. 2. Fixation curves for Elayapattuwa Soil Series; Zn (a), B (b), Cu (c) and Mn (d).

Greenhouse pot experiment

Results of the greenhouse pot experiment are given in Table 3. Opt treatment gave the highest biomass yield showing the practicability of nutrient recommendation using soil analysis and sorption studies for this soil. Rice biomass yield was greatly reduced with no application of N and P (67 and 42%, respectively) and moderately reduced in treatments with no application of S (Table 3). Biomass yield decrease without K and Zn application were 16 and 19%, respectively, while biomass yield decrease without Mg and Mo application were 10 and 8%, respectively. Addition of B Cu, Mn and Fe decreased the biomass yield by 6, 9, 5 and 6%, respectively confirming that the soil had sufficient amounts of B, Cu, Mn and Fe and that further addition of these nutrients decrease yield possibly due to toxic effects and imbalances (Table 3).

Field experiment

Soil nutrient contents in experimental plots at 6 weeks after planting

Experimental plots treated with optimum nutrient recommendation had all nutrients at sufficient levels (Table 4). Lowest levels of nutrients were observed in soil of the control plot treatment where no fertilizer was applied. Addition of each nutrient increased its availability in soils (Table 4), but higher rates of certain nutrients affected the availability of other nutrients in the soil showing interactions between some nutrients. For example, high amounts of P reduced the availability of Zn. The Zn and P antagonistic effect has been earlier reported for an acidic Ultisol in Bagladesh (Ahmad *et al.,* 1992) and Low Humic Gley (Batalagoda series) soils of the Low Country Intermediate zone (Bandara *et al.,* 2004). Availability of K was increased with the addition of K fertilizer and T_6 treatment which received 60 kg K/ha was sufficient to supply the optimum level (117 mg K/kg soil) for plant. The treatment receiving P at the rate of 35 kg P/ha, provided sufficient level of P to the soil. Further addition of P is unnecessary and is an additional cost. Results also revealed that addition of S, Mg, and Zn increased their availability in the soil up to optimum levels. Levels of P and K could be reduced to 35 and 60 kg/ha, respectively, as these amounts provided P and K to reach levels exceeding than the optimum levels. Similarly, Mg and S fertilizer levels could be reduced to 15 and 25 kg/ha, respectively. This may be due to the supply of these nutrients to the soil through other natural sources such as rock weathering, irrigation water and rains. With the nutrients provided based on the present DOA fertilizer recommendation, N and Zn contents in soil were below the critical levels while S was close to the critical level. In this treatment, P, K, Mg, B, Cu and Mn in soil were above the critical levels, but only Cu and Mn reached levels above the optimum (Table 4). This indicates that the present DOA fertilizer recommendation does not supply all nutrients at sufficient levels to maintain the optimum soil fertility for rice crop.

Table 3. Dry matter yield of above ground biomass of rice (g/pot).

Treatment	Mean dry weight of shoot (g/pot)	Relative dry matter yield in comparison to the Opt (%)
Opt	3.07^{a}	100
Opt -N	1.02^{j}	33
Opt -P	1.77^{h}	58
Opt -K	2.59^{d}	84
Opt -S	2.16^{f}	70
Opt -Mg	2.77^{bc}	90
Opt +B	2.89^{b}	94
Opt +Cu	2.81^{b}	91
Opt +Mn	2.93^{ab}	95
Opt -Mo	2.84^{b}	92
Opt -Zn	2.50^{de}	81
Opt +Fe	2.91^{ab}	94
No Fertilizer	1.15^{ij}	37
CV %	4.61	

Note: Means followed by the same letter along the column are not significantly different at 5% probability level by DMRT.

Table 4. Mean soil nutrient content at the maximum tillering stage of rice crop.

Treatment	Criteria	Nutrient content in soil (mg/kg)								
		N	P	K	S	Mg	B	Zn	Cu	Mn
T_1	Opt	92	41	132	36	144	0.76	1.3	2.4	22
T_2	N_1	67	33	128	33	149	0.82	1.8	2.6	26
T_3	P_0	82	10	134	34	152	0.81	1.9	2.6	27
T_4	P_1	68	26	126	28	148	0.71	1.5	2.4	25
T_5	K_0	88	34	72	32	156	0.79	1.8	2.5	29
T_6	K_1	83	31	120	28	138	0.72	1.6	2.3	22
T_7	Mg_1	88	28	112	29	127	0.74	1.7	2.4	25
T_8	Mg_0	83	32	128	30	121	0.78	1.8	2.6	26
T_9	S_1	74	35	126	26	138	0.73	1.7	2.5	26
T_{10}	S_0	78	32	128	14	136	0.77	1.8	2.6	28
T_{11}	Zn_0	84	38	133	29	148	0.74	0.7	2.7	28
T_{12}	DOA	62	17	88	12	120	0.68	1.2	2.4	24
T_{13}	No fert	40	10	71	13	121	0.81	0.7	2.5	26
Critical level		-	12	78	12	96	0.4	1.5	1.0	4
Optimum level		100	24	117	24	156	0.8	2.0	2.0	12

Note: Critical and optimum levels adapted from nutrient disorders and nutrient management in rice by Dobermann and Fairhurst (2000).

Nutrient contents in plants from field experimental plots at 6 weeks after planting

Treatment 1 with optimum levels of nutrients gave healthy plants with each nutrient at levels above the critical level (Table 5). Whenever a deficient nutrient in soil was not applied in a treatment, the rice plants showed low levels of deficient nutrient consistently. In addition, deficient levels of some nutrients affected other nutrients in the plant showing either antagonistic or synergistic effects (Table 5). Application of 175 kg N/ha provided plants with sufficient quantity of N, but a lower rate of 150 kg/ha also proved to be sufficient (Table 5). Addition of P at the rate of 35 kg P/ha was sufficient to provide the optimum P level in plant (Table 5) and further addition of P did not give any beneficial effect. Application of 60 kg K/ha provided the optimum K level in the plant (Table 5), while application of K beyond 60 kg K/ha did not provide a further beneficial effect. The DOA recommendation of 42 kg K/ha provided K to reach plant K levels just above the optimum limits (Table 5). Levels of other nutrients in the soil also influenced the P and K contents in plant tissues. High Mg negatively influenced the K content in plants while positively affecting S, B, Cu, Zn and Mn contents. Similarly, high levels of P reduced the availability of Zn in soil, subsequently reducing the plant uptake (Tables 4 and 5). This interaction has been earlier reported by Bandara *et al.* (2004) for Batalagoda soil series in the Low Country Intermediate zone. Even though the Opt treatment gave the highest nutrient contents in plants, application of 175 kg N, 35 kg P, 60 kg K, 25 kg S, 15 kg Mg and 2.0 kg Zn/ha (Treatments T_3, T_6, T_7 and T_9) was sufficient to supply respective elements to plants at optimum levels. Some of the nutrients in this treatment were at lower rates than the optimum level calculated through initial soil analysis and fixation curves. One possible reason for the comparable nutrient contents in plants with lower levels of nutrients added could be the supply of those nutrients through irrigation and rain water to the field. Kendaragama (1988) reported that 23.5 kg K/ha/season was received to the rice field from irrigation water. Therefore, when making fertilizer recommendation for irrigated rice, supply of nutrients from other sources, particularly from irrigation water and rain, should also be considered.

Grain yield

In 2004 *Yala*, the highest yield was recorded by Opt treatment (T_1) in which N, P, K, Mg, S and Zn were provided at rates of 175 N, 60 P, 120 K, 25 Mg, 50 S and 2 Zn kg/ha, respectively (Table 5). However, in 2004/05 *Maha* season, the highest yield was recorded by 60 kg K/ha (T_6) with all other nutrients levels as in the Opt treatment. This same Opt treatment gave the highest biomass yield in the pot experiment proving the validity of fertilizer recommendation using this new approach. Addition of N at the rate of 150 kg/ha with all other required nutrients gave yields which were not significantly different from the yield with Opt treatment (T_1) (Table 5). Addition of 35 kg P and 60 kg K/ha gave yields which were not significantly different from the yield at 65 kg P and 120 kg K/ha. These reduced rates of nutrients have given similar grain yields compared to the calculated optimum levels. This may be due to supply of nutrients from other sources like irrigation and rainwater as described above.

With the optimum N, P and K levels, addition of Mg, S and Zn further increased the grain yield (Table 5). Response to applied N, P, K, Zn on grain yield was highly significant in both seasons, but significant effect of S on the grain yield was observed only in *Maha* season (Table 5). Although addition of Mg increased the yield, the yield increases were not significant in both seasons (Table 5). Optimum levels of Mg, S and Zn fertilizers for high yields must be evaluated by repeating the experiment with few levels of each nutrient. Results also indicated that present fertilizer recommendation for Elayapattuwa soil series in LCDZ has to be revised considering the nutrient availability and nutrient fixation capacity of this soil. Results further indicated that nutrient use efficiency in this soil can be increased by using optimum and balanced nutrient recommendation as earlier reported by Bandara and Silva (2001) and Bandara *et al.* (2005) for Batalagoda and Kurunegala soil series.

Table 5. Nutrient content in plants in each treatment at maximum tillering stage and grain yield of rice at maturity.

Treatment	Criteria	Nutrient content in plants (%)					Nutrient content in plants (mg/kg)					Mean grain yield (t/ha)[†]		
		N	P	K	S	Mg	B	Zn	Cu	Mn		2004 *Yala*	2004/05 Maha	Mean
T_1	Opt	3.8	0.28	2.5	0.24	0.24	12.0	40	12	58		7.38[a]	5.73[a]	6.56[a]
T_2	N_1	3.0	0.32	2.2	0.23	0.23	9.0	30	10	42		6.82[ab]	5.32[bcd]	6.08[abc]
T_3	P_0	3.4	0.12	2.1	0.21	0.19	10.0	44	9	38		5.45[c]	4.86[e]	5.16[c]
T_4	P_1	3.2	0.27	2.3	0.23	0.23	12.0	43	11	49		7.26[a]	5.63[ab]	6.45[ab]
T_5	K_0	2.9	0.26	1.4	0.21	0.24	9.0	38	11	52		5.94[c]	4.83[e]	5.38[bc]
T_6	K_1	3.3	0.29	2.5	0.24	0.22	13.0	42	10	56		7.35[a]	5.82[a]	6.59[a]
T_7	Mg_1	3.2	0.29	2.3	0.23	0.22	12.0	40	11	50		7.25[a]	5.67[ab]	6.46[ab]
T_8	Mg_0	3.4	0.24	2.6	0.19	0.16	9.0	34	9	37		6.83[ab]	5.42[bcd]	6.13[abc]
T_9	S_1	3.2	0.28	2.7	0.24	0.23	9.1	41	10	54		7.26[a]	5.68[ab]	6.47[ab]
T_{10}	S_0	2.8	0.27	2.3	0.14	0.21	8.0	36	9	42		6.99[ab]	5.13[cde]	6.06[abc]
T_{11}	Zn_0	3.4	0.31	2.2	0.19	0.22	10.0	10	10	48		6.18[bc]	4.75[e]	5.46[bc]
T_{12}	DOA	3.1	0.24	2.1	0.14	0.17	9.0	26	10	48		6.26[bc]	5.04[de]	5.65[bc]
T_{13}	No fert	2.0	0.15	1.4	0.12	0.12	5.6	9	8	26		3.62[d]	2.55[f]	3.08[d]
Critical	Level	2. 5	0.10	1. 5	0.15	0.12	5. 0	15	5	20	CV%	7.1	6.6	11.5
Optimum	Level	2.9-4.0	0.2-0. 4	1.8- 2.6	0.16-0. 3	0.15-0. 3	6-15	25-50	7-15	40-150	T	*	*	*
											TxS	-	-	Ns

Note: Critical and optimum levels were adapted from Nutrient disorders and nutrient management in rice by A. Dobermann and T. Fairhurst (2000);
* significant at 5% level of probability; Ns - Not significant; [†] Means followed by the same letter in each column are not significantly different at 5% probability level by DMRT.

CONCLUSIONS

Elayapattuwa soil series in the Low Country Dry zone of Sri Lanka is slightly acidic with moderate levels of available nutrient contents. Soil N, P and Zn contents were below the critical levels while Fe was in excess. Potassium was near critical ranges while B, Cu, Mn and Ca were in sufficient ranges. Soil Mg and S were in slightly lower than the optimum levels. Fixation of K, Cu and Mn were low in this soil while fixation of P, S, B and Zn were comparatively higher. Optimum fertilizer rate calculated based on the initial soil analysis, fixation curves and optimal nutrients levels adapted from Dobermann and Fairhurst (2000) and Portch and Hunter (2002) performed better both in pot and field experiments giving high biomass and grain yields, respectively. The yield data were significantly higher in the Opt treatment than the present DOA fertilizer recommendation. Therefore, site-specific approach of nutrient recommendation for rice can be used to increase the yield of rice grown in this soil. Suggested nutrients rates to be applied to rice crop grown at the experimental site in Elayapaththuwa soil series at Maha Illuppallama were 175 kg N, 35 kg P, 60 kg K, 25 kg S, 15 kg Mg, and 2 kg Zn/ha to obtain high yield. However, further refinement of this fertilizer recommendation is necessary before adapting it. In future, this methodology can be adapted to formulate site-specific fertilizer recommendation for rice.

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