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Crop Yields, Nutrient Uptake and Apparent Balances for Lentil-Mungbean-T. Aman Rice Cropping Sequence in Calcareous Soils

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Abstract: Nitrogen (N), phosphorus (P), potassium (K), sulphur (S), zinc (Zn) and boron (B) nutrition of the Lentil-Mungbean-T. Aman rice sequences (L-M-R) are important for increasing crop productivity and improving soil fertility. Field experiments on Lentil-Mungbean-T. Aman rice cropping sequence was conducted in calcareous soils of Madaripur, Bangladesh tomeasure the crop yields, nutrient uptake and apparent balances. Four fertilizer treatments were considered *viz.* absolute nutrient control (T_1); farmer's practice (T_2); AEZ basis fertilizer application (T_3) and soil test basis fertilizer application (T_4). The treatments were compared in a randomized completely block design with three replications over two consecutive years. The average yields of lentil, mungbean and T. aman rice ranged from 675 to 1067 kg ha^{-1}, 1075 to 1801 kg ha^{-1} and 3049 to 4843 kg ha^{-1}, respectively showing T_4 as the best treatment. Soil test basis fertilizer application (T_4) exhibited the highest nutrients uptake by all tested crops. The apparent balance of N and K was negative; however it was less negative for T_2 and T_4 treatment. The apparent P balance was positive in T_2, T_3 and T_4 but negative in T_1. Positive S balance observed in T_3 and T_4 but negative in T_1 and T_2. Zinc and B balance in the sequence was positive in case of T_3 and T_4. Considering highest yield, gross margin and soil fertility have been recommended that the soil test basis fertilizer application is profitable for Lentil-Mungbean-T. Aman rice cropping sequence in calcareous soils of Bangladesh. The study clearly indicate a possibility for the re-adjustment of the N, P, K, S and micronutrients (Zn & B) fertilizer doses for the different rice-based cropping sequence in different agro-ecological zone of Bangladesh.

Keywords: CropYields, Nutrient Uptake, Nutrient Balance, Lentil-Mungbean-T. Aman Rice, Calcareous Soil

1. Introduction

Calcareous soils under the agro-ecological zone-Low Ganges River Floodplain which belongs to Madaripur,Sariotpur, Faridpur, Pabna, Natore, Gopalgonj, eastern part of Kushtia, Magura and Narail districts of Bangladesh. Rice is the staple crop in calcareous soils of Madaripur, but some farmers are grown lentil and vegetables in Rabi and jute in Kharif season [1]. Lentil (*Lens culinaris*), mungbean (*Vigna radiata*) and T. aman rice (*Oryza sativa* L.) grown sequentially in an annual rotation constitute a Lentil-Mungbean-T. Aman cropping sequence.

Nitrogen (N), phosphorus (P), potassium (K), sulphur (S), zinc (Zn) and boron (B) nutrition of the Lentil-Mungbean-T.

Aman rice sequences are important for increasing crop productivity and improving soil fertility. Soil nutrients (N, P, K, S, Zn and B) play an important role for regulating the supply of nutrients to plant [2]. Several studies have shown that intensive rice-based cropping system including rice-wheat (RW), rice-rice cause's remarkable depletion of soil nutrients and threat to crop productivity [3]. Besides the farmers are following imbalanced use of fertilizers for crop production which leads to degrade soil fertility [4]. Farmers generally use fertilizers on single crop basis, not the cropping sequence. High yielding varieties of crops uptake higher amount of nutrients from soils resulting in depletion of soil organic matter and deterioration of soil fertility, poses a great threat to sustainable crop production. Moreover, continuous cropping without adequate replacement of removed nutrients and nutrient loss through erosion, leaching, and gaseous emission have caused depletion soil fertility as well as soil organic matter [5, 6]. Furthermore, low levels of plant nutrients (macro and micro) in calcareous soil accompanied with improper nutrient management are constraints for food security and malnutrition. Plant nutrition research can be helped to eliminate the constraints and sustaining food security and well-being of people without affecting the environment [7].

The bulk of literature indicates that, apart from residue management, cropping system productivity may become sustainable through integrated use of organic and inorganic sources of nutrients [8]. Hence, monitoring of crop yields, nutrient concentration, nutrient uptake and balance that to assist for understanding of plant and soil nutrients status and in devising fertilizer management strategies for both individual crop and a cropping sequence in specific agro-ecological zone. Quantification of the loss or gain of nutrients under different cropping sequence has been less attended. Nutrient balance is an important tool for assessing the nutrient reserve in soils. Crop nutrient balance is a difference between nutrients applied to soil in relation to its removal by crops and leaching loss. Negative nutrient balance may limit crop yield and deplete soil fertility and positive nutrient balance shows nutrient accumulation [9]. It is hypothised that the current fertilizer recommendation could be improved for a definite cropping sequence. Thus, the aim of this study was to compare sequence crop yields, nutrient uptake and nutrient balance for the Lentil-Mungbean-T. Aman rice cropping sequence with varying fertilizer management practices.

2. Materials and Methods

2.1. Site Description

The field experiments were conducted consecutive two years (2009-10 and 2010-11) at Regional Pulses Research Station, Bangladesh Agricultural Research Institute (BARI) Madaripur (23° 10′ 53″ N latitude and 90° 11′ 28″ E longitude) liesat an elevation of 7.0 m above the sea level. The calcareous soils of Madaripur, Bangladesh is medium high land with loamy textured belongs to Gopalpur series (Soil taxonomy: Aquic Eutrochrepts) under the Low Ganges River Floodplain (Agro-Ecological Zone-12). The experimental site has subtropical humid monsoon climatic condition which is characterized by comparatively high monsoon rainfall, high humidity, and high temperature. Average temperature ranged from 13.0 − 36.1°C and average annual rainfall varied from 1500−2200 mm around the year.

2.2. Experiment Set-up

The experiments were carried out over the three crop seasons such as Rabi (mid October to mid March), Kharif-I (mid March to mid June) and Kharif-II (mid June to mid October).

2.2.1. Treatment and Layout

The experiment consisted of four treatments for each crop-absolute nutrient controls (T_1); farmer's practice (T_2); AEZ basis fertilizer application (T_3) and soil test basis fertilizer application (T_4).Descriptions of the different treatments are given in Table 1.

Table 1. *Rates of fertilizers (kg ha^{-1}) for lentil, mungbean and T.aman rice.*

Treatments	Lentil	Mungbean	T. aman rice
Control (T_1)	**Control**	**Control**	**Control**
F. practice (T_2)	$N_{23}P_{30}K_{15}$	$N_{23}P_{15}K_8$	$N_{70}P_{10}K_{15}$
AEZ(T_3)	$N_{15}P_{18}K_{10}S_5Zn_{0.5}B_{0.5}$	$N_{15}P_{18}K_9S_8$	$N_{66}P_6K_{12}S_7Zn_1$
STB (T_4)	$N_{21}P_{23}K_{30}S_{18}Zn_2B_2$	$N_{21}P_{23}K_{30}S_{18}Zn_2B_{1.5}$	$N_{100}P_{14}K_{66}S_6Zn_{1.5}B_1$

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The unit plot size was 4 m × 3 m for all crops having the spacing of 30 cm × 05 cm for lentil, 30 cm × 10 cm for mungbean and 20 cm × 15 cm for T. aman rice. The layout was kept undisturbed for the cropping sequence over two years.

a. Fertilizers application and seed sowing

Full amount of fertilizers, except urea in rice was applied to respective plot during final land preparation. Urea was applied in three equal splits for T. aman rice. The sources of N, P, K, S, Zn and B were urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate and boric acid, respectively. The first crop lentil (var. BARI Masur-6) were sown on mid November, 2nd crop mungbean (BARI Mung-6) were sown on end of March and the 3rd crop T. aman rice (var. BRRI dhan33) seedlings (30 days old) were transplanted on mid July.

b. Intercultural operation

Intercultural operations like irrigation, weeding and plant protection measures (insecticides and fungicides) were done as and when required. The transplanted rice seedlings were nursed properly in the seedbed.

2.2.2. Data Collection and Statistical Analysis

The crops were harvested after maturity. Data on yield contributing characters of all test crops were recorded from 10 randomly selected plants/hills from each plot. Data on yields (kg ha^{-1}) were recorded from whole plot technique. Analysis of variance (ANOVA) for the yield and yield contributing characters and different nutrient content was done following the principle of F-statistics and the mean values were separated by Duncan's Multiple Range Test (DMRT) [10] using MSTAT-C software.

2.3. Soil and Plant Samples Analysis

Soil samples at 0-15 cm were collected before establishing the experiment and after completion of two cycles of the cropping sequence from each treatment plot. Plant samples (straw and grain) against each treatment plot were oven-dried at 70°C for 48 h and finely ground.

The initial and final soil samples were analyzed for soil pH and organic matter by Nelson and Sommers [11] method; total N by Microkjeldahl method [12]; exchangeable K by 1N NH_4OAc method [13]; available P by Olsen and Sommers [14] method; available S by turbidity method using $BaCl_2$ [15]; available Zn by DTPA method [16]; available B by azomethine-H method [17].

Ground plant samples were digested with di-acid mixture (HNO_3-$HClO_4$) (5: 1) as described by Piper [18] for the determination- concentration of N (Micro-Kjeldahl method), P (spectrophotometer method), K (atomic absorption spectrophotometer method), S (turbidity method using $BaCl_2$ by spectrophotometer), Zn (atomic absorption spectrophotometer method) and B (spectrophotometer following azomethine-H method).

2.4. Soil Solution, Rain and Irrigation Water Samples Analysis

Soil solution was collected at intervals of 15 days starting from the date after transplantation to harvest of rice crop with the help of 50 ml plastic syringe. The samples were brought to the laboratory immediately after collection, filtered through Whatman No. 42 filter paper and preserved for the determination of P, K, S, Zn and B. Rain water was collected by rain sampler after each rain event. Irrigation water was measured by V-Notch method [19]. Collected rain and irrigation water was preserved for determining the nutrients (P, K, S, Zn and B). Soil solution, rain and irrigation water samples were analyzed for concentration of P, K, S, Zn and B followed same as plant samples analysis method.

2.5. Nutrient Leaching Loss Estimation

Nutrient loss was calculated from the results of percolation water and nutrient concentration in soil solution. In calculating percolation water (L m^{-2}) the formula $Q = -K_wAT.\Delta\Psi_h/\Delta z$ given by Hanks and Ashcroft [20] was used. Where, Q = Quantity of water K_w= Hydraulic conductivity, A = Area, T = Time, H = Difference in hydraulic potential and Z = Difference between two points taking 0 to downward as negative. The hydraulic potential was again calculated by adding the component potentials as $\Psi_h= \Psi_m+ \Psi_p+ \Psi_z$ where h, m, p, and z represent hydraulic, metric, pressure and gravitational potentials. Negative Q was considered as downward movement of water.

2.6. Hydraulic Conductivity

We determined the saturated hydraulic conductivity in the laboratory by constant head method [21]. Soil samples were collected from 0-15 cm depth using core samplers in triplicate. The hydraulic conductivity was calculated by using Darcy's equation as

$$K_w= -\frac{QL}{AT\Delta H} \text{ cm hr}^{-1} \tag{1}$$

Where, K_w= Saturated hydraulic conductivity (cm hr^{-1}), A= Cross sectional area of the sample in cm^2, T= Time in minute, Q= Quantity of water (ml) passing through the sample in time 'T', L= Length of the sample in cm, ΔH= Hydraulic head difference (Length of sample+ height of water above the sample) in cm.

2.7. Nutrient Uptake and Apparent Balance Calculation

Crop nutrient uptake was calculated from the nutrient (N, P, K, S, Zn and B) concentration and the straw and grain yields [22]. Apparent nutrient balance for the Lentil-Mungbean-T. Aman rice cropping sequence (average of two years) was computed as the difference between nutrient input and output [9]. The inputs were supplied from (i) fertilizer (ii) rainfall (iii) irrigation water (iv) BNF (biological nitrogen fixation) and the outputs were estimated from crop uptake and leaching loss in a cycle.

2.8. Physiological Efficiency (PE)

Physiological efficiency (PE) was calculated according to Equation-

$$PE = \frac{Y-Y_0}{U-U_0} \tag{2}$$

Where, Y is the yield of the fertilized plot, Y_0 is the yield of the unfertilized plot, U is the total nutrient uptake in above ground crop biomass with fertilized plot and U_0 is the total nutrient uptake in above ground crop biomass with unfertilized plot [9].

2.9. Economic Analysis

Added cost and added benefit were calculated. Besides, the gross return was calculated on the basis of different treatments which were directly related to the price of product. Cost of cultivation was involved with wage rate (land preparation, weeding, seed sowing and fertilizers application), pesticides, irrigation and fertilizers cost. Land used cost or rental value of land was not considered here. Marginal benefit cost ratio (MBCR) is the ratio of marginal or added benefit and cost. To compare different treatments combination with one control treatment the following equation was applied [23].

$$MBCR\ (overcontrol) = \frac{Grossreturn(Ti) - Grossreturn\ (To)}{VC(Ti) - VC\ (To)} = \frac{Addedbenefit\ (overcontrol)}{Addedcost\ (overcontrol)} \quad (3)$$

Where, T_i = T_2,......... T_4 treatments; T_0 = Control treatment; VC= Variable cost; and

Gross return = Yield × price

3. Results

3.1. Yields

The grain and stover yields of lentil and mungbean exhibited significant variation due to different fertilizer management practices in the consecutive two years (Table 2). The grain yields (mean of two years) ranged from 675 to 1067 kg ha^{-1} in lentil and 1075 to 1801 kg ha^{-1} in mungbean. The highest grain yields of lentil (1067 kg ha^{-1}) and mungbean (1801 kg ha^{-1}) was recorded from soil test basis fertilizer application (T_4) followed by AEZ basis fertilizer application (T_3) treatment. The control (T_1) treatment gave the lowest grain yield of 675 and 1075 kg ha^{-1} in lentil and mungbean, respectively. In case of stover yields both of lentil and mungbean, the effects of treatments were statistically differed with some exception and significantly highest value found in T_4 treatment. The lowest stover yields of lentil and mungbean were found in control T_1 treatment in both the years.

The grain and straw yields of T. aman rice (3rd crop) responded significantly to different fertilizer management practices in both the years (Table 2). The grain yield recorded from the fertilizer application on AEZ basis (T_3) and soil test basis fertilizer application (T_4) was statistically identical and higher than farmer's practice (T_2) and control treatment although T_4 treatment dominated over T_3 treatment. In case of straw yield, the treatments AEZ basis fertilizer application (T_3) and soil test basis fertilizer application (T_4) differed significantly in 1st year but in 2nd year they were statistically alike while soil test basis fertilizer application dominated over T_3. The lowest grain and straw yields were found in the control treatment. The grain yield (2 years' average) of T. aman rice varied from 3049 to 4843 kg ha^{-1}.

Soil test based fertilizer treatment gave the highest yields among the treatments and the increased grain yield to 58% in lentil, 68% in mungbean and 59% in T. aman rice over control (T_1) treatment. On the other hand this increased was 17 and 40 % in lentil, 14 and 41% in mungbean and 25 and 45 in T. aman rice, respectively in T_2 and T_3 (Table 2).

***Table 2.** Effect of fertilizer management practices on grain and straw/stover yields of crop in Lentil-Mungbean-T. Aman rice cropping sequence.*

Treatment	Grain yield (kg ha^{-1})				Stover yield (kg ha^{-1})		
	1st year	2nd year	mean	% of increase over control	1st year	2nd year	mean
Lentil							
Control (T_1)	720d	630d	675	-	1800b	1667c	1734
F. practice(T_2)	810c	765c	788	17	2025b	1962b	1994
AEZ(T_3)	900b	990b	945	40	2228b	2259ab	2244
STB (T_4)	1053a	1080a	1067	58	2687a	2700a	2694
CV (%)	4.95	4.60	-	-	6.36	6.99	-
$LSD_{0.05}$	102	98.6	-	-	76.6	87.7	-
Mungbean							
Control (T_1)	1010c	1141c	1075	-	2113c	2226d	2170
F. practice (T_2)	1189b	1264b	1226	14	2269b	2306c	2288
AEZ(T_3)	1440ab	1599b	1519	41	2503ab	2597b	2550
STB (T_4)	1713a	1888a	1801	68	2688a	2724a	2706
CV (%)	6.35	5.37	-	-	6.43	3.95	-
$LSD_{0.05}$	101	99.3	-	-	141	160	-
T. aman rice							
Control (T_1)	3189c	2910c	3049	-	3299c	3035c	3167
F. practice (T_2)	3875b	3722b	3798	25	3996b	3977b	3987
AEZ(T_3)	4394ab	4454a	4424	45	4498b	4568a	4533
STB (T_4)	4789a	4897a	4843	59	4888a	4987a	4938
CV (%)	5.98	4.95	-	-	3.86	4.88	-
$LSD_{0.05}$	385	447	-	-	379	449	-

Values within the same column with a common letter do not differ significantly ($P<0.05$)

3.2. Nutrient Concentration and Deficiency Determination in Grain

Grain nutrient concentration (mean of two years) of test crops- lentil, mungbean and T. aman rice and critical values are presented in Tables 3. The nutrients concentration of lentil due to different fertilizer management practices ranged from 3.91 to 4.08% N, 0.23 to 0.26% P, 0.76 to 0.79% K, 0.09 to 0.11% S, 56.8 to 61.9ppm Zn and 12.0 to 13.5ppmB. In case of mungbean, nutrient concentration varied in different treatment from 3.22 to 3.36% N, 0.22 to 0.25% P, 1.28 to 1.35% K, 0.08 to 0.10% S, 26.0 to 27.7 ppm Zn and 12.1 to 14.4 ppm B. Further in T. aman rice, concentration also ranged due to fertilizer treatments from 1.46 to 1.50% N, 0.22 to 0.24% P, 0.23 to 0.28% K, 0.065 to 0.090% S, 45.0 to 46.4 ppm Zn and 17.6 to 19.3 ppm B. Comparisons between test crops nutrients values and critical values through fertilizer management practices showed in Table 3. Different nutrient management practices exhibited the deficiency of N in lentil, mungbean and T. aman rice except T_3 and T_4 treatments which showed slightly sufficient in lentil. The highest N deficiency (critical value minus grain concentration) showed 0.09% in lentil, 0.41% in mungbean, and severe N deficiency 1.54% in T. aman rice, respectively for T_1 treatment. The minor N deficiency found in mungbean for T_4 treatment. Phosphorus deficiency in lentil, mungbean and rice crop was showed minor due to different treatment. Severe deficiency of K showed in lentil and T. aman rice, but in mungbean showed K deficiency in all the treatment. The highest K deficiency was calculated from T_1 and lowest was T_4 treatment in all the test crops (Table 3). Different treatment showed deficiency of S in lentil, mungbean and T. aman rice. There was minor affected of Zn in lentil and moderately affected of Zn in mungbean and T. aman rice due to different treatments. Lentil and mungbean showed deficiency of B in all the treatments while the highest B deficiency found in T_1 and lowest in T_4 treatment. The 3rd crop T. aman rice crops showed B sufficiency in all the treatments (Table 3).

Table 3. *Comparison between the grain nutrients concentration of lentil, mungbean and T. aman with critical values due to different fertilizer management practices.*

Treatment	N	P	K	S	Zn	B
Lentil	**(%)**				**ppm**	
Control (T_1)	3.91	0.23	0.76	0.09	56.8	12.0
F. practice (T_2)	3.99	0.25	0.77	0.10	57.8	12.2
AEZ(T_3)	4.04	0.24	0.78	0.11	60.6	13.2
STB (T_4)	4.08	0.26	0.79	0.11	61.9	13.5
Critical value	4.00	0.30	1.80	0.20	60.0	20.0
Mungbean						
Control (T_1)	3.22	0.22	1.28	0.08	26.0	12.1
F. practice (T_2)	3.25	0.23	1.31	0.09	26.4	12.3
AEZ(T_3)	3.31	0.24	1.32	0.09	27.5	14.0
STB (T_4)	3.36	0.25	1.35	0.10	27.7	14.4
Critical value	3.63	0.26	1.75	0.20	35.0	27.0
T. aman rice						
Control (T_1)	1.46	0.22	0.23	0.065	45.0	17.6
F. practice (T_2)	1.48	0.23	0.24	0.075	45.7	18.0
AEZ(T_3)	1.49	0.23	0.27	0.080	46.2	18.8
STB (T_4)	1.50	0.24	0.28	0.090	46.4	19.3
Critical value	3.00	0.23	1.20	0.15	60.0	15.0

Nutrient critical values source: [24, 25, 26, 27].

3.3. Nutrient Uptake

Different fertilizer management practices have made significant effect to uptake of N, P, K, S, Zn and B by lentil, mungbean and T. aman rice (Table 4). The soil test basis fertilizer application (T_4) showed significantly higher nutrients uptake by all the test crops over the other treatments. The second highest uptake was observed in T_3 which was followed by T_2. The nutrient uptake followed the order: N>K>P>S>Zn>B. The lower nutrient uptake was observed in control (T_1) treatment by all the test crops. The total uptake of nutrients by crops (lentil+mungbean+T. aman) ranged from 167 to 270 kg N ha^{-1}, 16.8 to 31.2 kg P ha^{-1}, 99.0 to 158 kg K ha^{-1}, 7.90 to 15.8 kg S ha^{-1}, 0.47 to 0.77 kg Zn ha^{-1} and 0.20 to 0.36 kg B ha^{-1}. Maximum total uptakes of all nutrients were found in STB (T_4) followed by AEZ (T_3). Minimum uptake was estimated in control (T_1) (Figures 1 & 2).

Table 4. *Effect of fertilizer management practices on nutrient uptake by crops of Lentil-Mungbean-T. Aman rice (grain+stover) cropping sequence (mean of two years).*

Treatment	N	P	K	S	Zn	B
	kg ha^{-1}					
Lentil						
Control (T_1)	44.8d	3.82c	19.8d	1.83d	0.090d	0.040c
F. practice (T_2)	54.0c	4.73bc	23.3c	2.29c	0.107c	0.050bc
AEZ(T_3)	63.9b	5.74b	27.0b	2.78b	0.130b	0.065ab
STB (T_4)	75.4a	7.08a	32.4a	3.59a	0.153a	0.075a
CV (%)	4.13	11.1	3.62	6.87	4.95	17.1
$LSD_{0.05}$	4.92	1.18	1.84	0.360	0.012	0.020
Mungbean						
Control (T_1)	62.9d	4.74c	43.5d	1.83c	0.077c	0.050b
F. practice (T_2)	70.3c	5.68c	48.2c	2.30c	0.085bc	0.054b
AEZ(T_3)	84.7b	7.01b	56.1b	3.02b	0.103ab	0.092a
STB (T_4)	98.2a	8.33a	63.0a	3.68a	0.117a	0.103a
CV (%)	2.12	9.73	3.08	11.1	10.6	12.6
$LSD_{0.05}$	3.35	1.25	3.24	0.60	0.021	0.019
T. aman						

Treatment	N	P	K	S	Zn	B
	kg ha^{-1}					
Control (T_1)	59.3d	8.16d	35.9d	4.22c	0.300c	0.111c
F. practice (T_2)	75.2c	10.8c	46.6c	6.05b	0.386bc	0.143b
AEZ(T_3)	87.4b	13.6b	55.4b	7.38ab	0.453ab	0.171a
STB (T_4)	96.9a	15.9a	62.6a	8.56a	0.502a	0.193a
CV (%)	1.34	9.13	2.53	12.7	13.21	9.24
$LSD_{0.05}$	2.14	2.21	2.54	1.67	0.108	0.028

Values within the same column with a common letter do not differ significantly (P<0.05)

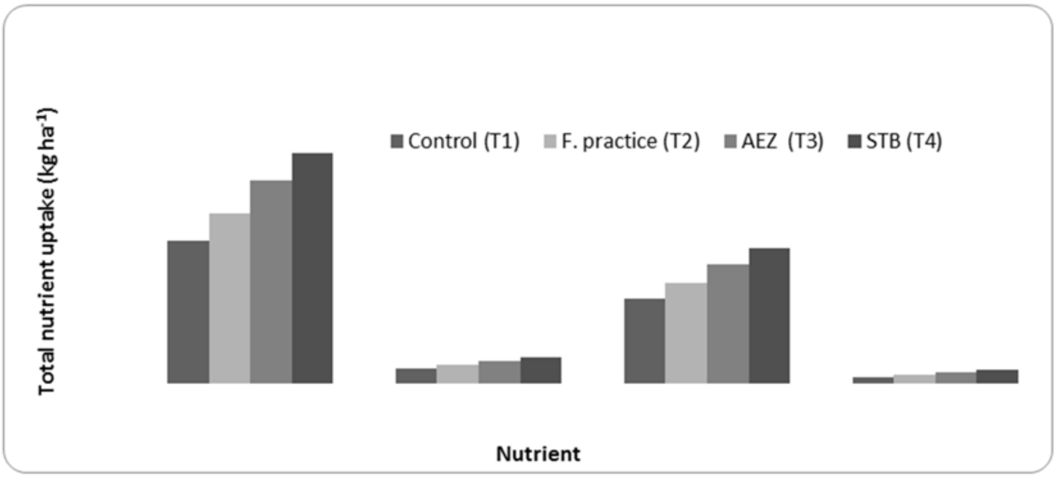

***Figure 1.** Effect of fertilizer management practices on nutrients uptake by crops under Lentil-Mungbean-T. Aman rice cropping sequence.*

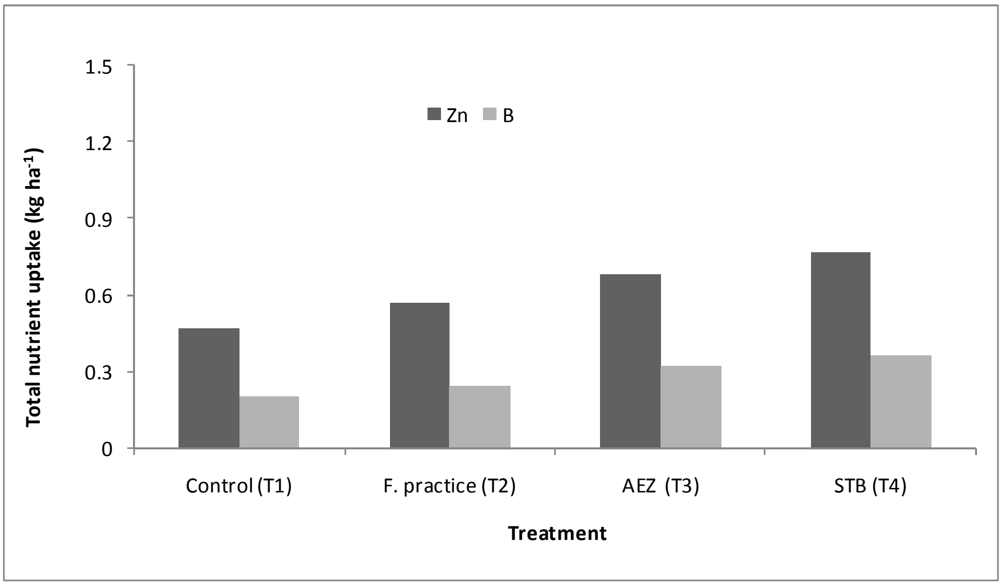

***Figure 2.** Effect of fertilizer management practices on zinc and boron uptake by crops under Lentil-Mungbean-T. Aman rice cropping sequence.*

3.4. Leaching of Nutrients

Leaching loss was estimated only for T. aman rice not for lentil and mungbean due to both crops are cultivated in dry land condition. Nutrient loss was calculated from the results of percolation water and nutrient concentration in soil solution. Nitrogen loss was ignored due to very low concentration in soil solution. Different nutrient management practices significantly favoured the loss of P, K, S, Zn and B element through leaching. The loss of nutrients (average of two years) through leaching ranged from 0.280 to 0.685 kg P ha^{-1}, 3.00 to 11.6 kg K ha^{-1}, 1.56 to 3.55 kg S ha^{-1}, 0.045 to 0.110 kg Zn ha^{-1} and 0.085 to 0.340 kg B ha^{-1}. The highest leaching loss values of nutrients were recorded from T_4 treatment which was significantly different with others treatment but statistically identical to T_3 treatment except B. The lowest nutrients loss values found in T_1 treatments (Table 5).

Table 5. *Effect of fertilizer management practices on nutrient loss through leaching under Lentil-Mungbean-T. Aman rice cropping sequence.*

Treatment	P	K	S	Zn	B
kg ha^{-1}					
Control (T_1)	0.280c	3.00c	1.56c	0.045b	0.085c
F. practice (T_2)	0.565b	8.44b	2.60b	0.045b	0.085c
AEZ(T_3)	0.635a	10.8a	3.32a	0.095a	0.295b
STB (T_4)	0.685a	11.6a	3.55a	0.110a	0.340a
CV (%)	4.81	4.91	12.9	12.9	4.07
$LSD_{0.05}$	0.052	0.828	0.716	0.019	0.016

Values within the same column with a common letter do not differ significantly (P<0.05)

3.5. Total Input and Output of Nutrients

The nutrient input mainly from fertilizer but in this estimate, the nutrients supply from fertilizer, rainfall, irrigation and N by symbiotic fixation were considered. We assumed 30 kg N ha^{-1} yr^{-1}added by symbiotic fixation. Annual input of N hence varied from 30 to 172 kg ha^{-1} yr^{-1}, P input ranged from 0.52 to 60.5 kg ha^{-1} yr^{-1}, and K input was on average 5.73 to 132 kg ha^{-1} yr^{-1}.The S input was average 3.12 to 48.1 kg ha^{-1} yr^{-1}and input of Zn varied from 0.071 to 5.57 kg ha^{-1} yr^{-1}. Boron input was estimated 0.28 to 4.82 kg ha^{-1} yr^{-1} (Table 6).

The output of nutrients (mean of two years) ranged from 167 to 270 kg N ha^{-1}, 17.0 to 32.0 kg P ha^{-1}, 102 to 170 kg K ha^{-1}, 9.44 to 19.4 kg S ha^{-1}, 0.512 to 0.882 kg Zn ha^{-1} and 0.286 to 0.771 kg B ha$^{-1.}$ The highest outputs of all nutrients were found in T_4 treatment and the lowest were in control (T_1) treatment (Table 6).

Table 6. *Total nutrients (N, P, K, S,Zn and B) input (fertilizer, rainfall, irrigation & BNF) and output (crops uptake & leaching loss) by Lentil-Mungbean-T. Aman rice cropping sequence due to different fertilizer management practices.*

Treatment	N	P	K	S	Zn	B
Nutrients input	kg ha^{-1}yr^{-1}					
Control (T_1)	30.0	0.52	5.73	3.12	0.071	0.28
F. practice (T_2)	146	55.5	43.7	3.70	0.072	0.29
AEZ (T_3)	126	42.5	36.7	24.9	1.57	0.82
STB (T_4)	172	60.5	132	48.1	5.57	4.82
Nutrient output	kg ha^{-1}yr^{-1}					
Control (T_1)	167	17.0	102	9.44	0.512	0.286
F. practice (T_2)	199	21.8	126	13.2	0.623	0.332
AEZ (T_3)	238	27.0	150	16.5	0.808	0.623
STB (T_4)	270	32.0	170	19.4	0.882	0.711

3.6. Physiological Efficiency of Nutrient

Physiological efficiency (PE) of nutrient was calculated from the ratio of economic yield (yield of fertilized plot minus yield of unfertilized plot) and nutrient uptake by the above ground biomass of crop (nutrient uptake of fertilized plot minus nutrient uptake of unfertilized plot).Physiological efficiency of N in lentil, mungbean and T. aman rice were 12.3 to 14.1, 20.3 to 20.6 and 47.1 to 48.9 kg kg^{-1}, respectively (Table 7). Among the treatments, physiological efficiency of N showed comparatively higher value in T_3 treatment in lentil and T. aman rice but PE of N was higher by T_4 in mungbean over the others treatment. The PE of P due to different treatment varied from 120 to 140, 160 to 202 and 231 to 283 kg kg^{-1}in lentil, mungbean and T. aman rice, respectively. Physiological efficiency of P greater in T_3 for lentil, in T_4 for mungbean and in T_2 for T. aman rice over the other treatments. In case of physiological efficiency of K and S in lentil, mungbean and T. aman rice showed the similar trend as physiological efficiency of N (Table 7). Lentil due to different nutrient management practices had physiological efficiency of Zn and B ranged from 6.22 to 6.75&10.8 to 11.3 kg g^{-1}, respectively.PE of Zn and B in mungbean varied from 17.1 to 18.8 and 10.6 to 37.7 kg g^{-1}, respectively. In T. aman rice, PE of Zn and B were found 8.71 to 8.98 and 21.8 to 23.4 kg g^{-1}, respectively. Among the different treatment, physiological efficiency of Zn observed higher in T_3 treatment in lentil and T. aman rice but it was higher for mungbean in T_2 treatment. The PE of B in all the test crops due to different treatment was estimated comparatively higher in T_2 treatment (Table 7).

Table 7. *Effect of fertilizer management practices on physiological efficiency of nutrient in crops of Lentil-Mungbean-T. Aman rice cropping sequence.*

Treatment	Physiological efficiency					
	(kg kg^{-1})				(kg g^{-1})	
	N	P	K	S	Zn	B
	Lentil					
Control (T_1)	-	-	-	-	-	-
F. practice (T_2)	12.3	124	32.3	245	6.64	11.3
AEZ(T_3)	14.1	140	37.5	284	6.75	10.8
STB (T_4)	12.8	120	31.1	223	6.22	11.2
	Mungbean					
Control (T_1)	-	-	-	-	-	-
F.practice (T_2)	20.4	160	32.1	321	18.8	37.7
AEZ(T_3)	20.3	195	35.2	373	17.1	10.6

Treatment	Physiological efficiency (kg kg-1)				(kg g-1)	
	N	P	K	S	Zn	B
STB (T_4)	20.6	202	37.2	392	18.1	13.5
	T. aman					
Control (T_1)	-	-	-	-	-	-
F.practice (T_2)	47.1	283	70.0	409	8.71	23.4
AEZ(T_3)	48.9	252	70.5	435	8.98	22.9
STB (T_4)	47.7	231	67.2	413	8.88	21.8

3.7. Apparent Nutrients Balance

An apparent nutrient balance was calculated considering the amount of added nutrient through fertilizer, rain, irrigation water and N supply by symbiotic fixation minus the amount of nutrient removed by crops and leaching loss. However, the nutrient balance did not account for the addition of N from rainfall, irrigation water, or gaseous losses. Apparent balance of N, P, K, S, Zn and B are shown in Figures 3 & 4. The balance was mainly affected by different fertilizer management practices. The apparent balance of N was negative in all the treatment and the soil depletion ranged from −53.0 to −137 kg N ha^{-1} yr^{-1}. In case of P balance which was negative in control treatment (T_1) and the P balance was positive in all the other treatment where P containing fertilizer was utilized. The balance of K was negative in all the treatments where the K mining ranged from −38.0 to −113 kg K ha^{-1} yr^{-1}. The highest K mining was recorded from AEZ basis fertilizer treatment (T_3) followed by control treatment and the lowest K mining was found in STB basis fertilizer treatment (T_4).The negative Sand Zn balance was observed in $T_1$and farmers practice (T_2) ranged from –6.32 to –9.50 and –0.44 to –0.55 kg ha^{-1} yr^{-1}, respectively. Remaining treatments showed positive balance ranged from 8.40 to 28.7 and 0.76 to 4.69 kg $ha^{-1}yr^{-1}$, respectively. Among the treatments, the maximum positive balance was observed in STB (T_4) followed by AEZ basis fertilizer treatment (T_3). Only control plot along with farmers practice treatments showed negative balance. Apparent balance for B was observed similar trend of Zn balance (Figures 3 & 4).

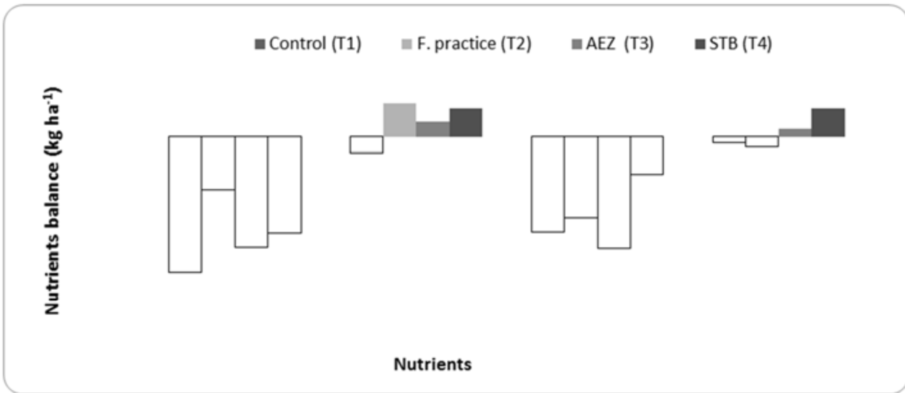

Figure 3. *Effect of fertilizer management practices on apparent nutrient balance of N, P, K and S in soil under Lentil-Mungbean-T. Aman rice cropping sequence.*

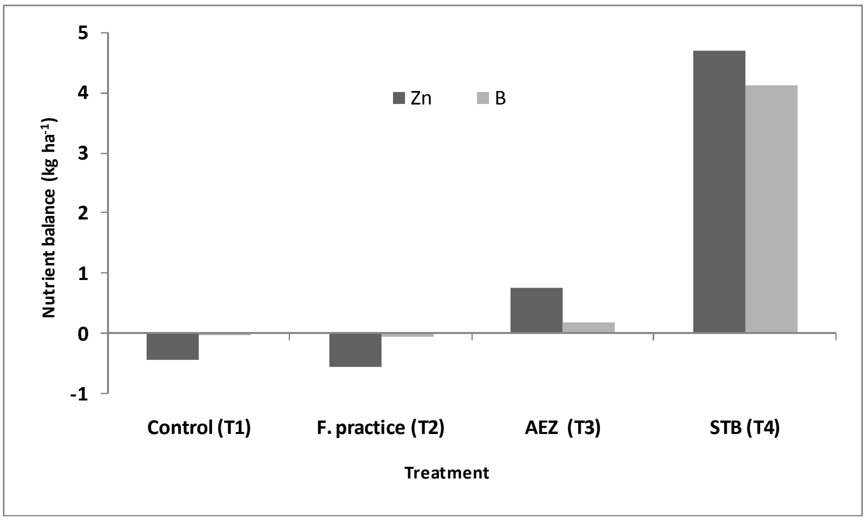

Figure 4. *Effect of fertilizer management practices on apparent balance of zinc and boron in soil under Lentil-Mungbean-T. Aman rice cropping sequence.*

3.8. Soil Fertility

Initial soil samples were collected from the experimental field and post harvest soil samples were also collected from each treated plot after two cycles of lentil-mungbean-T. aman rice cropping sequence for analyzing different soil properties viz. soil pH, organic matter, total N and available P, K, S, Zn and B. The initial and post harvest soil results are presented in Table 8. Initially the soil pH was 7.3, but after completion of two crop cycles and incorporation of mungbean stover and other crop residues in soil, the pH remained unchanged although minor variation existed. A minor change in soil fertility occurred from initial status due to different fertilizer management practices over two years. Soil test basis fertilizer application (T_4) tended to maintain the initial fertility or increased slightly (Table 8). The treatment T_4 showed an encouraging effect on organic matter, N, P, S, Zn and B only. Potassium (K) slightly decreased in all plots over the initial status. The available S, Zn and B content of the soil slightly decreased when they were not applied (T_1 and T_2), but remained almost static or increase when applied (Table 8).

Table 8. *Initial and postharvest soil fertility status after two cycles of Lentil-Mungbean-T. Aman rice cropping sequence due to different fertilizer management practices.*

Treatment	pH	OM (%)	Total N (%)	K meq.100 g^{-1}	P µg g^{-1}	S	Zn	B
Initial	7.3	1.42	0.063	0.15	14.0	18.0	1.20	0.14
Control (T_1)	7.3	1.44	0.064	0.13	14.0	17.0	1.18	0.12
F. practice (T_2)	7.2	1.47	0.065	0.13	15.0	17.9	1.18	0.13
AEZ(T_3)	7.2	1.51	0.067	0.13	15.0	18.2	1.21	0.14
STB (T_4)	7.2	1.57	0.073	0.14	15.5	19.0	1.26	0.16

3.9. Economic Analysis

Gross returns varied in different treatments under Lentil-Mungbean-T. Aman rice cropping sequence which was directly related to the price that received from the product. The gross returns were highest (Tk. 263958 ha^{-1} yr^{-1}) in the treatment T_4 followed by T_3 and T_2 and the lowest was in control treatment (Table 9). Cost of cultivation was involved with plowing, wage rate, pesticides, irrigation and fertilizers cost. Data on cost and return analysis showed that the maximum gross margin (Tk. 73817 ha^{-1} yr^{-1}) over control was calculated from T_4 and minimum from T_2. The gross margin by T_4 was increased three to four fold over farmer practice (T_2) due to get higher crop yield. The highest marginal benefit cost ratio (6.61) was obtained from T_3 followed by T_4 (3.74) and T_2 (2.81). Considering the marginal benefit cost ratio (MBCR) T_3 treatment showed ranked first followed by T_4. However, the cost of production of T_3 (Tk. 68218ha^{-1} yr^{-1}) was lower than T_4 (Tk.84694 ha^{-1} yr^{-1}) (Table 9).

Table 9. *Economic analysis of Lentil-Mungbean-T. Aman rice cropping sequence affected by different fertilizer management practices.*

Treatment	Variable cost	Gross return	Added cost over control	Added benefit over control	Gross margin over control	MBCR
	Tk. ha^{-1} yr^{-1}					
Control(T_1)	57800	163247	-	-	-	-
F. practice(T_2)	68682	193848	10882	30601	19719	2.81
AEZ(T_3)	68218	232210	10418	68963	58545	6.61
STB (T_4)	84694	263958	26894	100711	73817	3.74

Input prices: Urea= Tk. 12 kg^{-1}, T.S.P= Tk. 22 kg^{-1}, MoP= Tk. 20 kg^{-1}, Gypsum= Tk. 6 kg^{-1}, Zinc sulphate= Tk. 120 kg^{-1}, Boric acid= Tk. 300 kg^{-1}, Rovral fungicide= Tk. 250 100 $^{-g}$,Bavistin fungicide = Tk. 200 100^{-g}, Ripcord insecticide= Tk. 105 100^{-ml}, Karate insecticide = Tk. 450500^{-ml}, Plowing= Tk. 1400ha^{-1}(one pass), Labour wage= Tk. 125 day^{-1}, Lentil seed= Tk. 65 kg^{-1}, Mungbean seed= Tk. 60 kg^{-1}, T.aman rice seed= Tk. 35 kg^{-1}.
Output price: Lentil= Tk. 60 kg^{-1}, Mungbean= Tk. 55 kg^{-1}, T.aman rice= Tk. 19 kg^{-1}, Straw rate (lentil) = Tk. 1 kg^{-1}, Rice straw= Tk. 1.25 kg^{-1}.

4. Discussion

The yields of all test crops were highly responded to soil test basis fertilization (T_4) followed by AEZ basis fertilization (T_3).The nutrient management practices have positive effect on the yields of lentil, mungbean and T. aman rice. Initially the soil fertility status of this study was very low to low. Significant yield increased was observed in soil test based fertilizer treatment (T_4) indicated that the treatment T_4 was more balanced than that of T_2 and T_3. This higher yield increase might be possible for more balanced fertilization in T_4 than that of other treatments. Islam *et al.* [28] and Kumar and Singh [29] are in agreement with the findings. Balanced fertilization through soil test based treatment produce higher yields of crops as well as sustains soil fertility. These results are supported by many of researchers [30, 31, 32, 33]. Lentil, mungbean and T. aman rice yields of second year were relatively higher in T_3 and T_4 treatments than that of first year. Comparatively higher yield was observed in second year probably due to incorporation of crop residues in addition with fertilization. Result of soil analysis was done after two crop cycles showed an increasing trend of soil fertility although some exception existed. With the inclusion of legumes in cropping sequence, the crop residues left back in the field contain nutrients especially nitrogen [29]. Nawab *et al.* [34] and Aggarwal *et al.* [35] also found that incorporation of green manure into soil enhanced the fertility and yield of crop.

Comparisons of nutrient concentrations of grain in this studywith critical values collected from different published articles [24, 25]. Grain legume handbook [27] revealed that K and S deficiency showed more pronounced in lentil, mungbean and T. aman rice. Nitrogen deficiency detected more in T. aman rice. In case of P showed slightly deficient in lentil and mungbean but slightly sufficient in rice for T_4treatment. Similar observations were made by Timsina *et al.* [36]; Saleque *et al.* [37]; Panaullah *et al.* [38]. Minor Zn deficiency detect in all crops for all the treatment, except T_3& T_4 in lentil, which showed slightly sufficient. aman rice maintained adequate levels of B in grain but B detection deficient in lentil and mungbean for all the treatment. The results are supported by the observation of Kalra (1998) [24] and Bell and Kovar [25].

The uptakes of N, P, K, S, Zn and B by the crops in this sequence were significantly different among the treatments. The annual nutrients input had come from fertilizer, rainfall, irrigation water and biological nitrogen fixation (Table 6), removal of N and K exceeded input for all treatments but P, S, Zn and B was not exceeded the input for T_3 and T_4 treatment. In this study, the maximum N uptake was found in STB (270 kg $ha^{-1}yr^{-1}$) followed by AEZ (T_3) and minimum was in control (T_1). This finding is in line with Timsina *et al.* [36] who reported that N uptake was consistently and significantly greater due to STB fertilizer management. The treatment STB showed highest phosphorus uptake (31.2 kg ha^{-1} yr^{-1}) and second by AEZ (26.4 kg $ha^{-1}yr^{-1}$). The lowest uptake was found in control (16.8 kg ha^{-1} yr^{-1}). Tarafder *et al.* [39] observed that an uptake of P ranged from 160 to 202 kg ha^{-1} yr^{-1} in potato-boro-T. aman rice cropping system. Increasing rate of K application through STB contributed great K uptake (158 kg ha^{-1} yr^{-1}). Shrestha and Ladha [40] found different amount of K uptake by sweet pepper–fallow–rice (203 kg ha^{-1}); sweet pepper–indigo–rice (318 kg ha^{-1}); sweet pepper–indigo + mungbean–rice (303 kg ha^{-1}); sweet pepper–corn–rice (467 kg ha^{-1}).Among the treatments, maximum S uptake was observed in STB (15.8 kg ha^{-1} yr^{-1}) followed by AEZ (13.2 kg ha^{-1} yr^{-1}) and the minimum was in control treatment (7.90 kg ha^{-1} yr^{-1}). Sulphur uptake in wheat-T. aus-T.aman cropping system varied from 20 to 47 kg ha^{-1} yr^{-1} [41]. The uptake of other nutrients (Zn and B) due to different nutrients management practices followed almost the same trend of N uptake. Zinc and B uptake results confirmed by Hossain *et al.* [42] and Debnath *et al.* [43].

The balance of N, P, K, S, Zn and B was affected significantly by different fertilizer treatment in this studied sequence. Under different fertilizer management practices, removals of nutrients (N and K) are substantial [44]. Study revealed that higher N mining was occurred in control plot as no fertilizers were used and less mining was observed in farmer practice (T_2) and soil test basis fertilizer treated plot. More N was added in soil through fertilizer as well as added mungbean biomass and other crop residues. Hence, the farmer practice and soil test basis fertilizer treatment (T_4) showed lesser mining of N. Kumar and Goh [45] also found minimum N mining from balanced fertilization. On the other hand, apparent balance of N was negative in all the treatment and the depletion ranged from −53.0 to −137 kg N ha^{-1} yr^{-1}. In rice-maize systems in Bangladesh, the apparent nutrient balance showed highly negative for N (–120 to –134 kg ha^{-1} yr^{-1}) [46]. Phosphorus balance was positive in all P treated plots except control treatment (T_1) with the highest positive value in soil test basis fertilization (T_4) than the other treatments. This result is agreements with the findings of Jahan *et al.* [47]. In rice-maize system in Bangladesh, the apparent P balance was found positive (15 to 33 kg ha^{-1}) [48]. Positive balance of P showed adequate in soil but plant tissue showed inadequate even under the high-fertilizer (STB) treatments [49, 50]. Constraints for achieving adequate P concentration in tissue and uptake could include unavailability of the applied P (due to chemical fixation, or inadequate moisture in the fertilizer zone) or inadequate rates; understanding the cause will require further investigation. The calcareous soil which contained large amounts of calcium (Ca) may have favored the long-term sorption of P by Ca compounds [51].

The balance of K was negative in all the treatments where the highest mining was in AEZ basis fertilizer treatment and second in control treatment. The negative K balance depends on crop uptake and leaching loss of nutrient. The K negative balance builds up higher mainly crops uptake than that of leaching loss. The highest K mining in AEZ basis fertilization over control treatment indicated that the highest uptake of K by test crops. The STB dose contributed lesser mining of K from soil for increased dosages of K fertilizer. Lesser negative value of K was also found by Yadvinder *et al.* [44] due to STB balanced fertilization. The results confirmed the declining trends in available soil K in many treatments and they are comparable with many other long-term studies in rice–rice and rice–wheat systems of Asia [52]. Biswas *et al.* [53] found that the apparent average annual K balances were all negative and ranged from –179 kg ha^{-1} yr^{-1} in jute–rice–rice to –39 kg ha^{-1} in rice–potato–sesame. The control and farmer practice treatments resulted negative S balance while AEZ (T_3) and STB (T_4) treatments maintained a positive balance. The AEZ (T_3) and STB (T_4) treatments seemed to contribute S build up in soil but low S detection in lentil, mungbean and T. aman rice which suggest an increased dosage of S fertilizer [49, 50]. Alam *et al.* [54] reported that S was in positive balance for both sole and integrated application of fertilizer and manure. Jahan *et al.* [47] corroborated that the negative balance was observed in control and farmers practice treatments was –1 to –8 kg $ha^{-1}yr^{-1}$.

Zinc and B balance was showed positive in AEZ (T_3) and STB (T_4) treatment that indicated currently used of these two fertilizers. Deficiency detection of Zn and B in lentil and mungbean in this system recommended for increase of Zn and B fertilization. Other studies have also showed positive balance of Zn and B in maize-mungbean-rice system when those were added [42]. Similar results corroborated by Jahan *et al.* [55] in a mono crop cultivation of T.aman rice where –0.08 to –0.31 kg Zn ha^{-1} yr^{-1} was in control and farmers practice and positive balance (1.12 to 1.61 kg Zn ha^{-1} yr^{-1})

was in AEZ and STB treatment.

Economic analysis exposed that the gross return and gross margin by T_4 was increased over farmer practice (T_2) and AEZ basis fertilizer application (T_3) but considering the marginal benefit cost ratio (MBCR) T_3 treatment showed ranked first followed by T_4.The fertilizer dose under T_3 were low however, the cost of production of T_3 (Tk. 68218 ha^{-1} yr^{-1}) was lower than T_4 (Tk. 84694 ha^{-1} yr^{-1}) (Table 9).Therefore, the gross margin and soil fertility indicated the treatment T_4 is preferable to T_3. Similar results corroborated by Malika *et al.* [56].

The above discussions suggest that soil test based of nutrients (N, P, K, S, Zn and B) recommendation need to be monitored, taking into account plant testing to obtain higher productivity.

5. Conclusion

Yields/productivity of tested sequence showed higher through soil test basis fertilization. The nutrient uptake by lentil, mungbean and T. aman rice were found to be higher in soil test basis treatment. Nutrients balances at the end of the cycle showed different results depending on the nutrient. The magnitude of negative balance of N and K was greater among the major nutrients. Nitrogen and K mining occur remarkably from the soil. So, the rates of application of these two nutrients should be increased. Considering the gross margin and soil fertility the soil test basis fertilizer management practice (STB) is economically profitable and viable for achieving sustainable crop yield. Results of the present study clearly indicate apossibility for the re-adjustment of the N, P, K, S and micronutrients (Zn & B) fertilizer doses for the different rice-based cropping sequences in different agro-ecological zone of Bangladesh.

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