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PRODUCTIVITY AND NUTRIENT BALANCE OF MUSTARD-MUNGBEAN-T. AUS-T. AMAN CROPPING PATTERN AS INFLUENCED BY NUTRIENT MANAGEMENT IN HIGH BARIND TRACT

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Abstract

Crop productivity can be icreased by cultivating three or more crops on the same piece of land in a year. In this case judicial nutrient management is important to achieve higher crop production without incurring loss to soil fertility. With this understanding a study was undertaken at the Farming System Research and Development (FSRD) site, Kadamshahor, Godagari under Rajshahi distract in three consequtive years of 2015-18 to find out an optimum fertilizer dose for Mustard-Mungbean-T. Aus-T. Aman cropping pattern in the High Barind Tract agroecological zone. There were five treatments: T_1: Soil test-based fertilizer dose (STB), T_2: STB + 5 t cowdung ha^{-1} as IPNS (Integrated Plant Nutrition System), T_3: STB + 25% NPK, T_4: STB + 25% NPK + 5 t cowdung ha^{-1} and T_5: Farmers' practice. Pooled analysis was done our three years data. The yield of all crops performed better in T_4 and in deed, this treatment demonstrated the highest system productivity (16.23 t ha^{-1}), production efficiency (47.73 kg ha^{-1} day^{-1}) and gross return (Tk. 342720 ha^{-1}). But gross margin (Tk. 283347 ha^{-1}) and marginal benefit cost ratio (2.09) was the highest in T_3. Treatment T_3 and T_4 increased N, P and K uptake by the crops in the cropping pattern. Apparent nutrient balance for N and K at system level was negative, with the K balance being more negative, while P balance was positive in all the treatments except farmer practice.

Keywords: 4-crop pattern, Crop Productivity, Crop Profitability, Nutrient balance

1. Introduction

The arable land in Bangladesh is declining with advancement of time and presently cropped area is 8.04 million hectare (BBS, 2024). Nevertheless, scope is limited to increase cultivable land, so some scope exists to increase cropping intensity (CI) from the present 198% to 400% by incorporating short duration crops like mustard, mungbean and aus rice in the T. Aman rice-based pattern. Recently with the development of short duration rice, opportunity arises to fit mustard and pulse crops in the pattern. Mustard production can be increased by 20-25% by using high yielding short duration varieties like Sarisha-14 and BARI

Sarisha-15. Pulses are important legume crops in Bangladesh because of their importance in food, feed and cropping systems. They are generally grown with little fertilization since they can meet their nitrogen requirement by symbiotic fixation of atmospheric nitrogen in the soil. Nevertheless, pulses supply substantial amount of nitrogen to the succeeding non-legume crops grown in rice-based cropping system (Islam *et al.,* 2024).

Soil nutrients (N, P, K, S, Zn, B etc.) play an important role for regulating the supply of nutrients to plant (Konrad *et al.,* 2001; Rahman *et al.,* 2024). High yielding varieties of crops uptake higher amount of nutrients from soils resulting in deterioration of soil fertility which in turn poses a great threat to sustainable crop production (Rahman *et al.,* 2022). Moreover, continuous cropping without adequate replacement of nutrient loss that occurs through erosion, volatilization, leaching, and denitrification is a great threat to sustainable soil fertility and crop productivity (Yu *et al.,* 2014; Tirol-Padre *et al.,* 2007; Islam *et al.,* 2024).

High Barind Tract (AEZ 26) is recognized as drought prone area in Bangladesh and its soil fertility is low compared to other parts of the country (Islam *et al.,* 2022). So, mustard and mungbean were chosen as component crop in four crop based cropping pattern by replacing Boro rice. Besides, mustard and mungbean are the low water consuming crops. T. Aus rice can be cultivated with minimum irrigation water as monsoon remains active during its growing period.

Considering the drone prone situation of Barind Tract, we have developed a 4-cropping pattern, Mustard-Mungbean-T.aus-T. aman rice with taking adequate care of soil fertility. Thus, a study was underetaken to find out optimum nutrient rate or fertilizer dose for achieving higher productivity and profitability in the 4-cropping pattern in High Barind area.

2. Materials and Methods

A field experiment was conducted at Farming System Research and Development (FSRD) site, Kadamshahar, Godagari under Rajshahi district in three consecutive years during 2015 to 2018 for the 4-cropping pattern, Mustard-Mungbean-T.aus-T. aman rice. The soil of the experimental plot belongs to Amnura series under High Barind Tract (AEZ # 26). The levels of the fertilizers were calculated on the basis of high yield goal as per Fertilizer Recommendation Guide - 2012. The chemical properties of soil are presented in Table 1. The experiment was designed with five treatments and laid out in a randomized complete block design with three replications. There were five treatments: T_1: Soil test-based fertilizer dose (STB), T_2: STB + 5 t cowdung ha^{-1} as IPNS (Integrated plant nutrition system), T_3: STB + 25% NPK, T_4: STB + 25% NPK + 5 t cowdung ha^{-1} and T_5: Farmers' practice. The sources of nutrients were urea for N, TSP for P, MoP for K, Gypsum for S, Zinc sulphate for Zn and Boric acid for B. The amount of mineralizable nutrients of cowdung were deducted and adjusted accordingly as per IPNS treatments. The nutrient packages for different crops under Mustard-Mungbean-T.aus-T. aman patternwere detailed in Table 2.

Table 1. Chemical properties of initial soil (0-15 and 16-30 cm depth) of the experimental field

Depth (cm)	pH	Organic matter (%)	K	Total N (%)	P	S	B	Zn
			meq/100g soil		µg/g soil			
0-15	7.4	1.0	0.23	0.06	15.3	6.3	0.18	0.16
16-30	7.8	0.87	0.21	0.05	7.8	10.6	0.17	0.29
Mean	7.60	0.94	0.22	0.06	11.55	8.45	0.16	0.23
	Slightly alkaline	Low	Medium	Very low	Low	Low	Low	Very low

The layout was kept for three years. Crop cycle was started with mustard as the first crop on November 2015. Cowdung was applied to the first crop (mustard) only. The unit plot size was 5m × 4m. The details of the varieties used and cultural operations adopted in different crop sequences are given in Table 3. For mustard, half of urea and all other inorganic fertilizer were applied at the time of final land preparation as per treatment specification. The rest of the urea was applied at 20 days after sowing just after irrigation. For mungbean, all the inorganic fertilizers were applied at final land preparation and mixed with soil. In case of T. aus and T. aman rice, all the fertilizers except urea were applied as basal. Urea was applied as top dressing in three equal splits at 15, 30 and 45 days after transplanting. Intercultural operations viz. weeding, thinning, irrigation, fungicide and insecticide spray were done in order to support normal plant growth. Fertilizer doses of mungbean was calculated and rationalized considering residual effect of nutrient (except N) applied to previous crop (mustard). After picking of pod the remaining plant parts were incorporated in the experimental plot in-situ.

Table 2. Nutrient packages for Mustard-Mung-T.aus-T.aman

Treatments	Nutrients (kg ha^{-1})					
	N	P	K	S	Zn	B
Mustard						
T_1:STB fertilizer dose (FRG- 2012)	86	23	38	27	2	1.5
T_2: IPNS with 5 t ha^{-1} as of T_1	71	15.5	24	27	2	1.5
T_3: T_1 + 25% NPK	108	29	48	27	2	1.5
T_4: IPNS with 5 t ha^{-1} as of T_3	93	21.5	38	27	2	1.5
T_5: Farmers' practice	71	15	25	16	-	-
Mungbean						
T_1:STB fertilizer dose (FRG- 2012)	20	15	16	-	-	-
T_2: IPNS with 5 t ha^{-1} as of T_1	20	15	16	-	-	-
T_3: T_1 + 25% NPK	25	19	20	-	-	-
T_4: IPNS with 5 t ha^{-1} as of T_3	25	19	20	-	-	-
T_5: Farmers' practice	-	-	-	-	-	-
T. aus rice						
T_1:STB fertilizer dose (FRG- 2012)	80	15.00	30.00	12	2	-
T_2: IPNS with 5 t ha^{-1} as of T_1	80	15.00	30.00	12	2	-
T_3: T_1 + 25% NPK	100	18.75	37.50	12	2	-
T_4: IPNS with 5 t ha^{-1} as of T_3	100	18.75	37.50	12	2	-
T_5: Farmers' practice	75	12.00	26.00	10	-	-
T. aman rice						
T_1:STB fertilizer dose (FRG, 2012)	80	15.00	30.00	12	2	-
T_2: IPNS with 5 t ha^{-1} as of T_1	80	15.00	30.00	12	2	-
T_3: T_1 + 25% NPK	100	18.75	37.50	12	2	-
T_4: IPNS with 5 t ha^{-1} as of T_3	100	18.75	37.50	12	2	-
T_5: Farmers' practice	75	12.00	26.00	10	-	-

Table 3. Details of cultural practices adopted for different crops

Crop	Cultivar	Seed rate (kg ha^{-1})	Spacing (cm^2)	Date of planting	Date of harvesting
Mustard	BARI Sarisha-15	7	Continuous line with 30 cm spacing	1st week Nov.	1st week Feb
Mungbean	BARI Mung-6	30	Broadcast	Last week Feb.	1st week May
T. aus	BRRI dhan48	40	20 x 15	2nd week May	1st week Aug
T. aman	BRRI dhan57	40	20 x 15	2nd week Aug	Last week Oct

Data on the yield and yield contributing characters of each crop were recorded from 10 randomly selected plants per plot. Yield of main and by-product of each crop under various treatments were measured in each plot (6 m^2) at physiological maturity stage. Data on yield of various crops in sequences were recorded and converted into ton per hectare. Total system productivity was calculated as summation of individual (component) crop yield of each cropping cycle. The productivity of different treatment under crop sequence was compared by calculating their economic rice equivalent yield using formula given by Ahlawat *et al.* (1981), where

$$REY = \frac{\text{Yield of each crop (t ha}^{-1}\text{) x Economic value of respective crop (Tk. t}^{-1}\text{)}}{\text{Price of rice grain (Tk t}^{-1}\text{)}}$$

Production efficiency: Production efficiency (PE) was calculated by taking total economic yield of the sequence on rice equivalent basis divided duration of crops (Jamwal, 2001)

$$PE = \frac{REY}{\sum Dc}$$

Where, REY= Rice equivalent yield in a sequence and Dc= Duration of crops in that sequence.

Marginal benefit cost ratio (MBCR): The economic analysis was done following the method suggested by CIMMYT (1988). The MBCR can be computed as the marginal value product (MVP) over the marginal value cost (MVC). It can be computed as

$$MBCR = \frac{\text{MVP (over control)}}{\text{MVC (over control)}}$$

The seed yield of component crops was recorded and mean data were tabulated.

Apparent nutrient balance: Apparent nutrient balance was estimated considering the total amount of nutrient added to the soil through different sources of nutrient management and the total amount of nutrient uptake by the crop(s) (crops grain and their straw) each year. This calculation was valid particularly for P and K while calculating N balance, a 30% N loss have been assumed through different losses (like leaching, denitrification and volatilization loss etc). Apparent nutrient balance was expressed in kg $ha^{-1}yr^{-1}$.

The mean annual apparent N balance for the total pattern was calculated using the following formula:

$X_a = (X_f + X_o + X_r + X_i + X_b + X_{cri}) - X_{rem}$

Where, Xa = Apparent gain (+) or loss (-) of N (kg ha^{-1})

X_f = N added through inorganic sources (kg ha^{-1})
X_o = N added through organic sources (kg ha^{-1})
Xr = N added through rainfall (kg ha^{-1})
Xi = N added through irrigation water (kg ha^{-1})
Xb= N added through BNF (kg ha^{-1})
Xcri= N added through crop residue incorporation (kg ha^{-1})
Xrem= N removed by crops and loss through different systems (kg ha^{-1}).

Non-symbiotic BNF during each rice season was estimated to be 40 kg ha^{-1}, as has been reported by Cassman *et al.* (1998). Symbiotic BNF by legumes was estimated to be 70% of total plant N uptake (Timsina *et al.,* 2006). Nitrogen losses through denitrification, leaching, and ammonia volatilization in rice were expected to be substantial (De Datta and Buresh, 1989). Based on other studies on N loss during rice and wheat seasons in similar environments (Regmi *et al.,* 2002; Timsina *et al.,* 2006; Rafique *et al.,* 2012), annual N loss of 30% of total N inputs from all sources was estimated for each treatment or cropping sequence. Apparent N balances were calculated from various treatments or sequences. On the other hand, the equations of annual apparent P and K balances were same. In this case, biological nitrogen fixation is not occurred. The annual apparent P or K balance was calculated using the following simple equation:

$$Y_a = (Y_f + Y_r + Y_i + Y_{cri}) - Y_{rem}$$

Where, Ya = Apparent gain (+) or loss (-) of nutrient (P or K) (kg ha^{-1})
Y_f = Nutrient (P or K) added through inorganic sources (kg ha^{-1})
Yr = Nutrient (P or K) added through rainfall (kg ha^{-1})
Yi = Nutrient (P or K) added through irrigation water (kg ha^{-1})
Ycri= Nutrient (P or K) added through crop residue incorporation (kg ha^{-1})
Yrem= Nutrient (P or K) removed by crops through different systems (kg ha^{-1}).

The nutrient concentration of different crop's grain and straw; and rain and irrigation water were followed as was reported by Hossain (2013). Pooled analysis was made statistically with open-source software R (R Core Team, 2024).

3. Results and Discussion

3.1 Effects of nutrient packages on mustard

Yield of mustard responded significantly to different nutrient packages (Table 4). From three-year pooled analysis, the highest seed yield (1.50 t ha^{-1}) was obtained from treatment T_4 where 25% NPK higher dose and IPNS approach was used. The second highest seed yield (1.42 t ha^{-1}) was observed in treatment T_3 where IPNS package was also applied and the lowest yield (1.18 t ha^{-1}) in farmers' practice plot (T_5). Treatments T_1 and T_2 gave statistically different seed yield of mustard which were 1.31 and 1.37 t ha$^{-1,}$ respectively. Better performance of yield components (data not shown) was contributed to higher yield in T_4.

The stover yield followed the similar order as was observed in seed yield. The T_4 (4.29 t ha^{-1}) also gave the highest stover yield while T_5 showed the lowest one as pooled analysis. The application of higher doses of fertilizer along with intergated use of chemical and organic manure migh enhance growth and yield contributing characters due to slow and uninterrupted releasing of plant nutrient resulted to higher seed yield of mustard (Hossain et al., 2016). Researchers also reported that the seed yield of mustard is increased with the higher dose of nutrient application (Mamun *et al.,* 2012).

Table 4. Yield of component crops in mustard-mungbean-T. Aus-T. Aman rice cropping pattern as influenced by nutrient treatments during 2015-2018 (Pooled data)

Treatments	Mustard (t ha^{-1})		Mungbean (t ha^{-1})		T.aus (t ha^{-1})		T. aman (t ha^{-1})	
	Seed	Straw	Seed	Straw	Grain	Straw	Grain	Straw
T_1	1.31 d	3.01 d	0.99 d	2.14 d	5.16 c	6.09 c	3.36 d	5.22 c
T_2	1.37 c	3.32 c	1.08 c	2.21 c	5.36 b	6.19 bc	3.51 c	5.43 b
T_3	1.42 b	3.91 b	1.16 b	2.27 b	5.43 ab	6.33 ab	3.59 b	5.46 b
T_4	1.50 a	4.29 a	1.26 a	2.38 a	5.55 a	6.39 a	3.77 a	5.69 a
T_5	1.18 e	2.81 e	0.88 e	2.06 e	4.49 d	5.55 d	2.99 e	4.92 d
LSD $_{(0.05)}$	0.04	0.14	0.04	0.04	0.17	0.16	0.07	0.13
CV (%)	5.58	6.16	6.06	5.88	6.30	5.68	5.08	6.51

Table 5. System productivity, production efficiency and profitability in mustard-mungbean-T. aus-T. aman rice cropping pattern as influenced by the treatments during 2015-2018 (Pooled data)

Treat	System REY (t ha^{-1})	Production efficiency (kg^{-1}ha^{-1}day^{-1})	Gross return (Tk ha^{-1})	Variable cost (Tk ha^{-1})	Gross margin (Tk ha^{-1})	MBCR
T_1	14.26	41.91	302165	31629	270536	2.11
T_2	14.99	44.08	317230	49863	267367	1.42
T_3	15.47	45.50	327085	43738	283347	2.09
T_4	16.23	47.73	342720	62092	280628	1.60
T_5	12.63	37.14	268305	15624	252681	-

Input (kg ha^{-1}): Urea: 16, TSP: 22, MoP: 15, gypsum: 6, zinc sulphate: 120, boric acid: 150, rice seed: 40, Mungbean seed: 100, Mustard seed: 80, powertiller (1 pass): 2250, irrigation (1 time): 750 and Labour: 200 (8 hours).

Output (kg ha^{-1}): Rice grain:23, Mustard seed: 50, Mungbean grain: 50, rice straw: 1

3.2 Effects of nutrient packages on mungbean

Nutrient packages influenced yield of mungbean (Table 4). The treatments T_4 which included 25% higher NPK dose and IPNS packages was the best for seed yield of mungbean (1.26 t ha^{-1}) among all other treatments. The second highest yield was 1.16 under the treatments T_3 while the lowest seed yield (0.88 t ha^{-1}) was found in farmers' practice treatment T_5. Treatment T1 and T2 showed statistically different which were 0.99 and 1.08 t ha^{-1}, respectively. The highest seed yield in the treatment T_4 contributed by higher number of pods $plant^{-1}$, number seed pod^{-1} and 1000-seed (data not shown). This might also be due to residual effect of organic manure in the succeeding crop. Tagoe *et al.* (2008) also found higher seed yield of soybean and cowpea with carbonized chicken manure. However, mungbean yield was low in four crop-based patterns. Lower seed yield might be due to environmental factors especially continuous rainfall at later stage which hampers pod picking as well as pest infestation (Flee beetle, Jasid and Thriphs) at the early and flowering stage. Stover yield of mungbean resembled with the seed yield (Table 4). Consequently, stover yield was the highest in T_4 and the lowest in $T_{5.}$ Tagoe *et al.* (2008) also found higher seed yield of soybean and cowpea with carbonized chicken manure.

3.3 Yield of T. aus rice

In the Kharif-I season; T. aus was cultivated in four crop based cropping pattern. Normally farmers land remains fallow in the season. Grain and straw yields were found the maximum in T_4 followed by T_3 and T_2 with the lowest in T_5 (Table 4). Higher grain yields in organic manure amended and higher fertilizer treatments were mainly contributed by a greater number of tillers $hill^{-1}$ and higher number of grains $panicle^{-1}$. Higher grain yield in organic manure amended treatments were probably due to the residual effect of cowdung.

3.4 Yield of T. aman rice

In the Kharif-II season, T. Aman rice is the common crop in Bangladesh. Nutrient treatments had significant impact on grain yield of rice (Table 4). In pooled data, similar to T. aus rice the T_4 (3.77 t ha^{-1}) gave the greatest grain yield followed by T_3 (3.59 t ha^{-1}). The farmers package T_5 (2.99 t ha^{-1}) showed the lowest grain yield of T. Aman rice. Higher fertilizer doses as well as organic amended treatments produced better yield components which eventually contributed to higher grain yield. It showed that organics applied to preceding crop left significant quantity of nutrient for the succeeding crop. The residual effect of cowdung on grain yield of rice during rainy season was almost comparable and significantly higher than inorganic indicating slow release of plant nutrient from manure. Hedge (1998) reported that organic source of nutrients applied to preceding crop can benefit the succeeding crop to a great extent. The T_4 (5.59 t ha^{-1}) also recorded the highest straw yield among all other treatments. The T_3 (5.46 t ha^{-1}) and T_2 (5.43 t ha^{-1}) showed idential straw yield with the lowest in T_5 (4.92 t ha^{-1}). The T_1 recorded 5.22 t ha^{-1} straw yield.

3.5 System productivity

System productivity is considered as rice equivalent yield (REY). The REY in four crop patterns varied significantly by nutrient treatment in pooled analysis (Table 5). The T_4 package which contained higher dose and cowdung as IPNS basis (16.23 t ha^{-1}) recorded the greatest REY among all other packages. The REY in T_3 and T_2 were 15.47 and 14.99 t ha^{-1}. The lowest REY was obtained from farmers business package T_5 (12.63 t ha^{-1}). Total productivity increased by 28.50%, 22.48%, 18.68% and 12.90% in T_4, $T_{3,}$ T_2 and T_1 over T_5, respectively. System productivity was observed higher with conjunctive use of higher rate of fertilizer and organic manure (CD). The results in the present study are in agreement with the findings of other researchers who also attained maximum crop productivity by combined application of chemical fertilizers and manures (Yang *et al.,* 2004; Rafique *et al.,* 2012). As organic manure not only provides macro and micronutrients and also improves soil physical properties (Bhattacharyya *et al.,* 2004) and soil microbial activities (Tiwari *et al.,* 1998).

3.6 Production efficiency (PE)

Production efficiency was influenced by nutrient treatment (Table 5). The T_4 (47.73 kg^{-1} ha^{-1} day^{-1}) gave the maximum PE followed by T_3 and T_2. The lowest PE was recorded in T_5 (37.14 kg^{-1} ha^{-1} day^{-1}). The IPNS with higher rate of nutrient treatment gave the greater PE due to higher REY. The result is agreement with the result of another research (Hossain *at al.,* 2016) who reported higher PE in IPNS treatment with poultry manure.

3.7 Cost and return analysis

Nutrient packages attributed a remarkable impact on variable cost, gross return, gross margin and marginal benefit cost ratio (MBCR) (Table 5). The variable cost, annual gross return and gross margin were considered for choosing suitable technology. In general, higher fertilizer doses treatment markedly enhanced the variable cost. Consequently, the T_4 had higher variable cost (Tk. 62092 ha^{-1}) due to higher cost of fertilizer and manure followed by T_2 (Tk. 49863 ha^{-1}) and T_3 (Tk. 43738 ha^{-1}) while farmers fertilizer package (T_5) recorded the lowest cost because of lower fertilizer inputs. Again, the T_4 had higher gross return (Tk. 342720 ha^{-1}) due to higher crop productivity. The result is agreement with the finding of another scientist (Hossain at al., 2016). The gross margin was the highest in T_3 (Tk. 283347 ha^{-1}) indicating that manure influenced the cultivation cost and eventually the gross margin. Gross return and gross margin were also the lowest in farmers fertilizer package (T_5). MBCR was higher in mineral fertilizer packages T_3 (2.09) and T_1 (2.11).

3.8 Nutrient Uptake and Apparent Balance

3.8.1 Nitrogen uptake and apparent balance

The availability of N and its uptake and utilization by crops are closely related to productivity, but are controlled by numerous abiotic and biotic factors in the soil-plant system, including cultivar, fertilizer input, weather, pests and management of soil, crop residue, irrigation, and drainage (Witt *et al.,* 2000; Dobermann and White, 1999; Yadvinder-Singh *et al.,* 2005; Islam *et al.,* 2018). From pooled data, in mustard, more than 60% of N uptake was removed by mustard stover (Table 6). However, total N uptake by mustard ranged from 120 to 173 kg ha^{-1}, while T_4 (grain-56.10 kg ha^{-1}, stover-116.26 kg ha^{-1}) showed the highest N uptake followed by T_3 (grain-53.11 kg ha^{-1}, straw-105.96 kg ha^{-1}) and the lowest in T_5 (grain-44.13 kg ha^{-1}, straw-76.15 kg ha^{-1}). These results indicated that N uptake is resembled with crop productivity. Similar to mustard, total N uptake by mungbean was also the highest in T_4 (grain-39.69 kg ha^{-1}, stover-38.08 kg ha^{-1}) and the lowest in T_5 (grain-27.72 kg ha^{-1}, stover-32.96 kg ha^{-1}). The result also revealed that N uptake by mungbean grain and straw was almost equal though grain N concentration was higher than that of mungbean stover. Lower seed yield of mungbean resulted to lower N uptake by mungbean grain. The T_4 also showed the maximum N uptake both in T. Aus (grain-74.93 kg ha^{-1}, straw-43.45 kg ha^{-1}) and T. aman rice (grain-50.90 kg ha^{-1}, straw-38.69 kg ha^{-1}).

The T_3 recorded second highest N uptake both in T. Aus (grain-73.31 kg ha^{-1}, straw-43.04 kg ha^{-1}) and T. aman rice (grain-48.47 kg ha^{-1}, straw-37.13 kg ha^{-1}). The lowest N uptake was obtained from farmer fertilizer package for both the rice crop. It is mentioned that T. aus removed more N than T. aman. The T. aus cultivar, BRRI dahn48 gave more crop yield than that of T. aman cultivar BRRI dhan57 resulted to higher N uptake. N uptake by grain in both rice is higher than that of straw. Nutrient treatments had an effect on system level grain, straw and total N uptake (Table 6). In system level, almost equal amount of N was removed by grain in all the treatments. The T_4, which included 25% higher NPK as IPNS basis recorded greatest N uptake by grain, straw and system level than all other treatments. The T_3 showed second highest N uptake and the lowest in T_5 in system level in said parameters. The T_4 showed the highest amount of N uptake for all component crops and system level total N uptake while the T_5 recorded the lowest N uptake. However, the four crop pattern mustard-mungbean-T.aus-T. aman removed on an average 350 to 460 kg N ha^{-1} annually. Total N uptake in system level was greater in higher fertilizer rate and integrated nutrient managements, i.e., with conjunctive use of fertilizers and organic manures (Rafique *et al.,* 2012). As organic manure not only provides stable supply of macro-and micronutrients (Kabeerathumma *et al.,* 1993), but also improves soil physical properties (Bhattacharyya *et al.,* 2004) and soil microbial activities (Tiwari *et al.,* 1998).

Apparent N balance was calculated as the difference between N inputs and N outputs. Apparent N balance indicates that N variations were related primarily to applied N from different sources, crop N uptake and N losses. Annual system-level N input for T_4 was greater than all other treatment (Table 7). Apparent N losses increased substantially with input N in sequence, demonstrating that N losses were proportional to the rate of fertilizer N. Considering non-symbiotic BNF of 40 kg ha^{-1} for rice crop, symbiotic BNF of 70% of the total N uptake by legume crops, and 30% N losses in the balance, the all-nutrient treatments had a negative N balance, which ranged from -65 to -74 kg ha^{-1}. However, T_1 and T_5 showed more negative balance -74.15 and -73.55 kg ha^{-1} (Table 7).

Table 6. N uptake (kg ha^{-1}) by grain and straw of crops and system in response to different treatments during 2015-2018 (Pooled data)

Treat.	Mustard		Mungbean		T.aus		T. aman		System		
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Total
T_1	48.99	81.57	31.19	34.24	69.66	41.41	45.36	35.50	195.20	192.72	387.92
T_2	51.24	89.97	34.02	35.36	72.36	42.09	47.39	36.92	205.00	204.35	409.35
T_3	53.11	105.96	36.54	36.32	73.31	43.04	48.47	37.13	211.42	222.45	433.87
T_4	56.10	116.26	39.69	38.08	74.93	43.45	50.90	38.69	221.61	236.48	458.09
T_5	44.13	76.15	27.72	32.96	60.62	37.74	40.37	33.46	172.83	180.31	353.14

Table 7. Inputs, outputs and balance of N (kg ha^{-1}) in response to different treatments during 2015- 2018 (Pooled data)

Treat	Input							Removal			Balance
	Fert.	Manu	Rain	Irri.	Residue	BNF	Total	T.uptake	Loss	Total	
T_1	266.00	-	3.11	7.56	45.34	126.23	448.24	387.92	134.47	522.39	-74.15
T_2	251.00	50	3.11	7.56	46.03	127.66	485.36	409.35	145.61	554.96	-69.6
T_3	333.00	-	3.11	7.56	47.45	130.44	521.56	433.87	156.47	590.34	-68.78
T_4	318.00	50	3.11	7.56	48.97	133.65	561.29	458.09	168.39	626.48	-65.19
T_5	221.00	-	3.11	7.56	43.95	123.79	399.41	353.14	119.82	472.96	-73.55

Table 8. P uptake (kg ha^{-1}) by grain and straw of crops and system in response to nutrient treatments during 2015-2018 (Pooled data)

Treat	Mustard		Mungbean		T.aus		T.aman		System		
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Total
T_1	5.90	4.82	5.45	9.63	15.48	7.92	10.08	6.786	36.90	29.15	66.05
T_2	6.17	5.31	5.94	9.945	16.08	8.05	10.53	7.059	38.72	30.36	69.08
T_3	6.39	6.26	6.38	10.215	16.29	8.23	10.77	7.098	39.83	31.80	71.63
T_4	6.75	6.86	6.93	10.71	16.65	8.31	11.31	7.397	41.64	33.28	74.92
T_5	5.31	4.50	4.84	9.27	13.47	7.22	8.97	6.396	32.59	27.38	59.97

Table 9. Inputs, outputs and balance of P (kg ha^{-1}) in response to nutrient treatments during 2015-2018 (Pooled data)

Treat	Input						Total uptake	Balance
	Fertilizer	Manure	Rain	Irrigation	Residue	Total		
T_1	68.00	-	0.91	1.08	11.64	79.26	66.05	13.21
T_2	60.50	30.5	0.91	1.08	11.82	102.4	69.08	33.32
T_3	85.50	-	0.91	1.08	12.19	97.21	71.63	25.58
T_4	78.00	30.5	0.91	1.08	12.64	120.71	74.92	45.79
T_5	39.00	-	0.91	1.08	11.33	50.08	59.97	-9.89

Table 10. K uptake (kg ha^{-1}) by grain and straw of crops and system in response to nutrient treatments during 2015-2018 (Pooled data)

Treat.	Mustard		Mungbean		T.aus		T. aman		System		
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Total
T_1	17.685	65.919	15.147	46.01	15.996	103.53	10.416	88.74	59.24	304.20	363.44
T_2	18.495	72.708	16.524	47.515	16.616	105.23	10.881	92.31	62.52	317.76	380.28
T_3	19.17	85.629	17.748	48.805	16.833	107.61	11.129	92.82	64.88	334.86	399.74
T_4	20.25	93.951	19.278	51.17	17.205	108.63	11.687	96.73	68.42	350.48	418.90
T_5	15.93	61.539	13.464	44.29	13.919	94.35	9.269	83.64	52.58	283.82	336.40

Table 11. Inputs, outputs and balance of K (kg ha^{-1}) in response to cropping pattern during 2015-2018 (Pooled data)

Treat	Input						Total uptake	Balance
	Fertilizer	Manure	Rain	Irrigation	Residue	Total		
T_1	114.00	-	9.08	19.5	77.20	219.78	363.443	-143.66
T_2	100.00	58.5	9.08	19.5	78.71	265.79	380.279	-114.49
T_3	143.00	-	9.08	19.5	81.08	252.66	399.744	-147.08
T_4	133.00	58.5	9.08	19.5	85.13	305.21	418.901	-113.69
T_5	77.00	-	9.08	19.5	73.49	179.07	336.401	-157.33

3.8.2 Phosphorus uptake and apparent balance

Generally, P uptake is low by plant in compared to N and K. Again, rice crop removed more P than legume and mustard crops. In mustard, T. aus and T. aman, P uptake was higher by grain than those of straw but P uptake by legume straw was more than that of legume grain (Table 8). Similar to N uptake, the P uptake by crops also resembled with those of crop yields. Thus, the T_4 removed more P for all the four crops in the sequence compared to all other treatments and followed by T_3 and the least in farmers doses T_5. In system level, total P uptake was greatest in T_4 (74.92 kg ha^{-1}) followed by T_3 and smallest in T_5.

System-level total P input was the lowest in T_5 (50.08 kg ha^{-1}) and the highest in T_4 (120.71 kg ha^{-1}), because the later treatment received more P through fertilizer, manure and crop residue incorporation (Table 9). Apparent annual balance of P differed due to nutrient treatment. The farmers package T_5 showed negative P balance (-9.89 kg ha^{-1}) indicating P doses were insufficient to maintain the crop productivity for long run. However, the other treatments got positive balance while the highest positive balance in T_4 (45.79 kg ha^{-1}).

3.8.3 Potassium uptake and apparent balance

In general K uptake was more by straw than that of grain for all the crops in the four corps sequence (Table 10). However, both rice crops removed more K than other crops like mustard and mungbean while the T. Aus removed most. Similar to N and P uptake, the T_4 showed the highest K uptake in all the crops in sequence followed by T_3 and the lowest by T_5. In system level, about 85% of system total K was removed by straw. The T_4 removed 418.90 kg ha^{-1} while it was 336.40 kg ha^{-1} in T_5.

System-level input K was lowest in T_5 and highest in T_4 among all the treatment (Table 11). Apparent annual balance of K differed due to nutrient treatment (Table 11). The balance was consistently negative in all treatments being most in T_5 (-157.33 kg ha^{-1}) and least in T_4 (-113 kg ha^{-1}) sequence.

4. Conclusions

The four-crop based cropping pattern, Mustard-Mungbean-T. Aus-T. Aman rice, has higher productivity, which however necessitates increased nutrient requirement. Organic manure played a significant role in increasing the productivity of all component crops in the cropping sequences. The results suggest that STB+25% NPK fertilizer on IPNS basis is a promising technology for higher crop yields and system productivity with less negative balance for N and K.

Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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