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Productivity Improvement in Coastal Region of Bangladesh through Improving Rice-based Cropping Patterns and Optimizing Nutrient Management

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The productivity of rice-based cropping systems in the coastal zones of eastern India and Bangladesh is low, and we hypothesized that optimizing nutrient management could increase the system productivity as well as farm income. Therefore, we conducted an on-farm study in Barguna district, the coastal zone of Bangladesh, from 2019 to 2021 to optimize nutrient management for two intensifiedrice-based new cropping patterns (CP$_1$: T. *Aus* rice-T. *Aman* rice-Sunflower and CP$_2$: T. *Aus* rice-T. *Aman* rice-Sweet gourd) for increasing crop productivity. The study considered five nutrient management packages namely, soil test-based (STB) fertilizer dose, STB fertilizer dose plus 25% NK, fertilizer dose as per the Fertilizer Recommendation Guide-2018, soil testing kit-based fertilizer dose, and farmers' applied fertilizer dose for both the cropping patterns. Higher profitability was obtained from the T. *Aus* rice-T. *Aman* rice-Sweet gourd pattern than the T. *Aus* rice-T. *Aman* rice-Sunflower pattern. The highest system productivity was achieved by the application of STB fertilizer dose plus 25% NK which increased the system productivity of CP$_1$ by 21% and 31% compared to the STB fertilizer dose and farmers' applied dose, respectively. The productivity of CP$_2$ with STB fertilizer dose plus 25% NK was increased by 31% over both the STB fertilizer and farmers' applied doses. The findings of the study indicate that intensified cropping patterns such as T. *Aus* rice-T. *Aman* rice-Sweet gourd with optimized nutrient supply (*i.e.,* STB fertilizer dose plus 25% NK) can be highly profitable for the coastal farmers.

(***Key words:*** *Coastal agriculture, Nutrient, Productivity, Economic profitability)*

The coastal zone agriculture of Bangladesh frequently faces climate variability effects more adversely than the other parts of the country (Dasgupta *et al.,* 2014; Karim, 2006; Mainuddin *et al.,* 2019). Rising sea levels, increased saltwater invasion and intrusion, and changing rainfall patterns along with more frequent extreme weather events are the reality of the coastal region (Bhuiyan *et al.,* 2012) which are directly impacting the crop productivity (Kabir *et al.,* 2019). Salinity in coastal soil and water varies significantly with space and time due to the consequences of variability in climate (Bhuyan *et al.,* 2023). Moreover, the salinity is unevenly distributed and varies with the land types of the coastal region but can retard crop growth and depress yield (Haque, 2006). Therefore, sustainable crop production is the main challenge for the coastal zone under rapidly changed climatic conditions.

Crop intensification in the salt-affected coastal region is essential to boost local crop production, which relies mostly on a single long-duration rice per

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year (Sarkar *et al.,* 2022). Moreover, the low-yielding traditional T. *Aman* (monsoon season) rice is usually harvested late (Paul *et al.,* 2021b; Shahadat *et al.,* 2019). After harvesting rice, most of the lands remain fallow due to excessive wet conditions, salinity, and so on.

Nowadays, sunflower is a very prospective dry-season oilseed crop for the coastal region after the harvest of *Aman* rice. Farmers also get good yields of sunflower; however, proper irrigation and drainage systems need to be ensured (Paul *et al.,* 2021a; Islam *et al.,* 2022). On the other hand, some pit-based vegetable crops like sweet gourd are grown by the farmers in the dry season because of high market price with less amount of irrigation. Therefore, there is a good scope to include sunflower or sweet gourd in rice-based cropping patterns of the coastal region especially when following high-yielding short-duration variety for *Aman* rice; however, cropping pattern-based nutrient management is then a major challenge (Bell *et al.,* 2019; Kabir *et al.,* 2019; Haque *et al.,* 2023).

In intensified cropping systems, nutrient requirements of monsoon rice and other dry season crops are still under question for the coastal zone (Bell *et al.,* 2019; Kabir *et al.,* 2019; Paul *et al.,* 2021b). In most of the cases farmers do not get satisfactory yields due to inadequate application of fertilizers (Mainuddin *et al.,* 2019; Sarkar *et al.,* 2022). Moreover, imbalanced crop nutrition endangers crop productivity and sustainability. Nutrient management ensures the supply of crop nutrients rationally considering the crop requirement to optimize productivity. Islam *et al.* (2022) suggest the use of balanced fertilizer in a vulnerable saline region to improve crop yields and sustainable intensification. They also reported that farmers of salt-affected coastal zones apply 12%, 70%, and 11% overdoses of N, P, and K fertilizers, respectively under two fully rice-based cropping patterns; however, the level of overdoses varies with farm size and category. Mostly high N and P fertilization with inadequate amounts of K, S, and other micronutrients are being applied in different soils. Moreover, the expected crop production might not be achieved due to spatial variation in levels of soil fertility. Therefore, a study was initiated with two research questions: (i) how the productivity of the coastal region can be increased by improving rice-based cropping patterns and optimizing nutrient management, and (ii) how much benefit can be obtained from improved cropping patterns with an optimized nutrient management package. Contrasting cropping patterns, T. *Aus* rice-T. *Aman* rice-Sunflower and T. *Aus*-T. *Aman* rice-Sweet gourd cropping patterns were tested to increase the system productivity and income of the farmers of the coastal region by optimizing the nutrient management package.

MATERIALS AND METHODS

Study area

The study was conducted at Sekendarkhali, Amtali (Latitude 22°02′30″ and Longitude 90°14′24″) of Barguna district (Fig.1) which is located in the agro-ecological zone (AEZ) 13. Amtali is an upazila of 2,71,000 people covering 720.75 km^2 of the total area of which 80% is under cultivation and the cropping intensity is 173% (BBS, 2013). Rice is extensively grown in this region, especially transplanted *Aman* rice.

Various degrees of soil salinity affect a major portion (46% of the total cultivable area) of the coastal zones (Ahmed *et al.,* 2020). The soil salinity of that region is seasonal and affects mostly the winter (*Rabi*) and pre-monsoon (pre-*Kharif*) season crops (Fig. 2). The salinity of canal waters varies from 0.65 to 7.52 dS m^{-1} (SDRI, 2015). Soil and water salinity starts to increase in November and reaches its peak in May-June, then again starts to fall on the onset of monsoon rainfall and with the flow of flood water from the north. The soil salinity levels of the study fields for both the patterns were also highest from May to June (Fig. 2). In the whole region, the underground water is saline up to 600-1000 ft (varies from place to place).

Climatic condition

May was the hottest month (33.7-34.2°C) during the study period and December to February were the coldest months (13.4-15.4° C) (Fig. 3). The maximum monthly rainfall (683 mm in 2019 and 579 mm in 2020) occurred in July. December was the driest month in 2019 and 2020. During the study period, ausrice received 1845 mm rainfall in

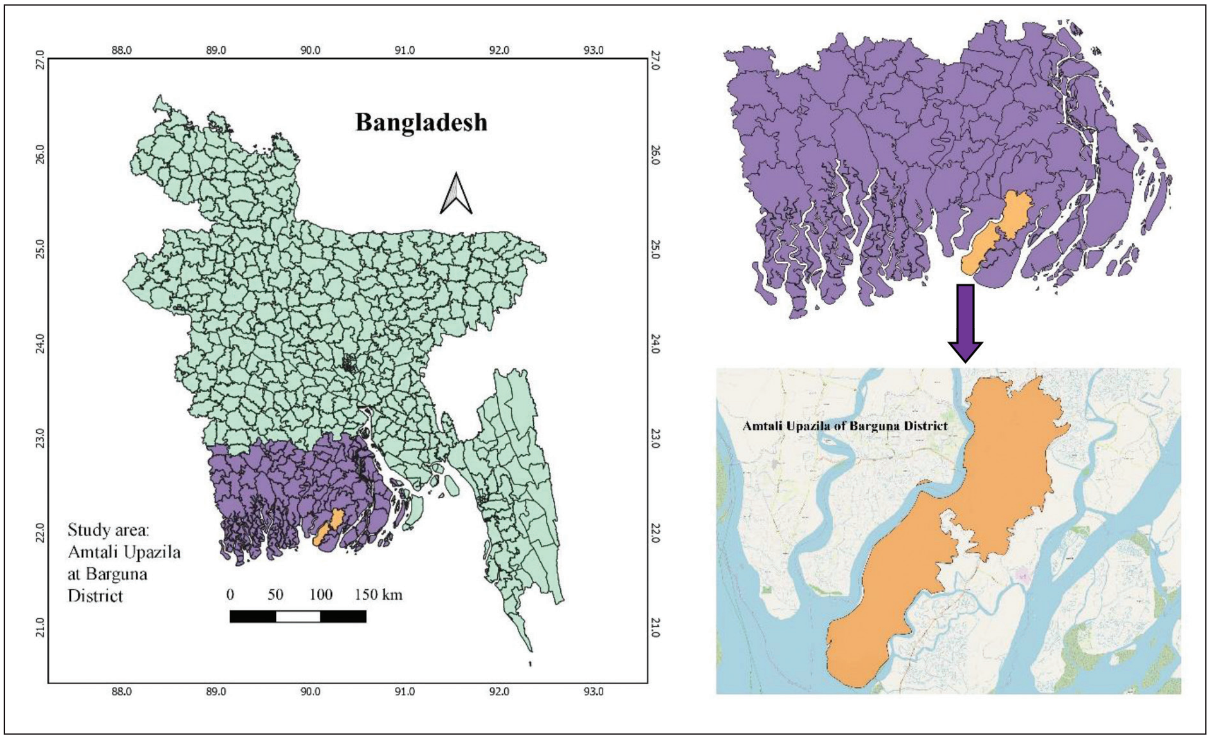

***Fig. 1.** The map of Bangladesh showing the study area*

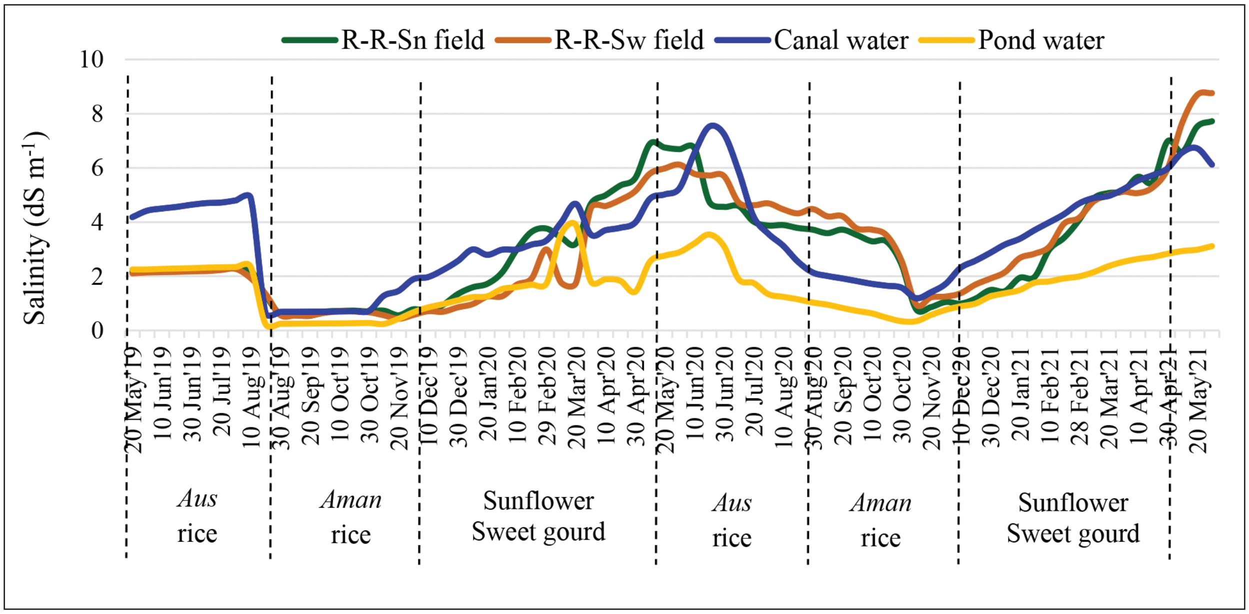

***Fig. 2.** Salinity levels of canal and pond water and in soils of the farmers' fields with T. Aus rice-T. Aman rice-Sunflower (R-R-Sn) and T. Aus rice-T. Aman rice-Sweet gourd (R-R-Sw) cropping patterns from May 2019 to May 2021. Vertical dashed lines represent the duration of respective cropping seasons*

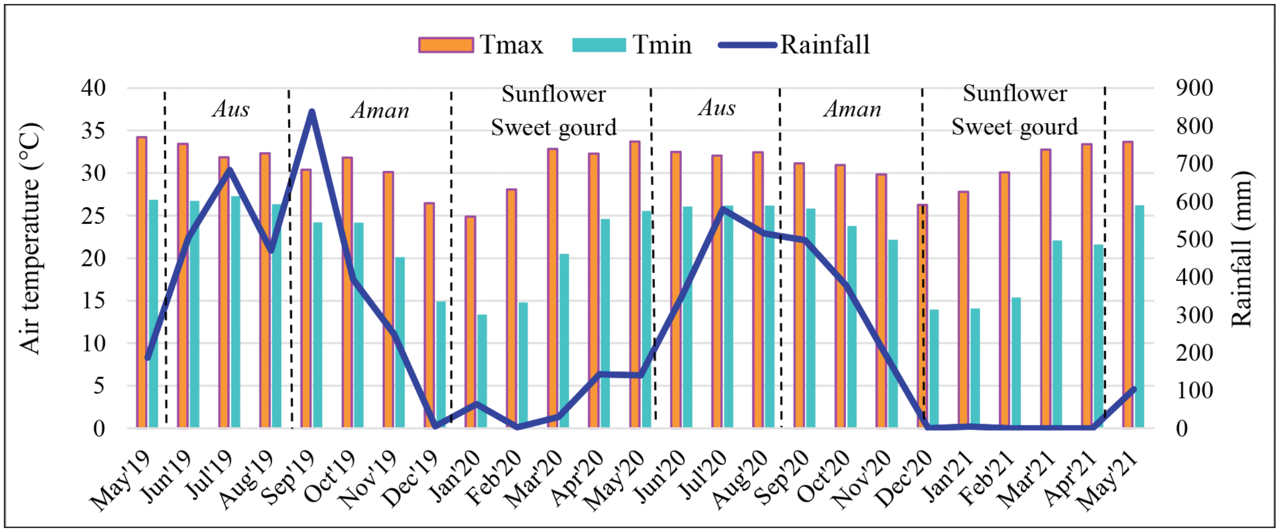

Fig. 3. *Monthly averages of maximum and minimum temperatures and monthly total rainfall of Barguna district from May 2019 to May 2021 (Source: Bangladesh Meteorology Department, Kalapara, Patuakhali)*

2019 and 1582 mm in 2020. The total rainfall during T. *Aman* rice was 1550 mm in 2019 and 1582 mm in 2020. However, in the dry month, sunflower and sweet gourd received minimal rainfall.

Experimental design and treatments

The study considered two cropping patterns, CP_1: T. *Aus* rice-T. *Aman* rice-sunflower and CP_2: T. *Aus* rice-T. *Aman* rice-sweet gourd. In both patterns, the effect of nutrient management was separately evaluated on individual crop yield, system productivity, economic benefit, nutrient uptake, and apparent nutrient balance. The main aim of the study was to find out the best nutrient management package for both cropping patterns to increase productivity. The study tested five nutrient management packages; NM_1: Soil test-based fertilizer dose, NM_2: Soil test-based fertilizer dose + 25% NK, NM_3: Fertilizer dose as per the Fertilizer Recommendation Guide of 2018 (FRG-2018), NM_4: Bangladesh Agricultural University (BAU) developed soil testing kit-based fertilizer dose, and NM_5: Farmers' applied fertilizer dose for both cropping patterns. However, in the case of CP_1, NM_4 nutrient management packages were not tested only for sunflower because of having no standard dose for that study area. The two separate experiments were designed for both patterns following the randomized complete block design with three dispersed replications. The unit plot size was 30 m^2.

Crop management

Both cropping patterns were started in 2019 with T. *Aus* rice. The details about crop varieties, their planting times, and harvesting times of both patterns are provided in Table 1. The initial soil samples were collected before the initiation of the study. The experimental lands were fertilized with N, P, K, and S in the form of urea, triple super phosphate, muriate of potash, and gypsum, respectively as per the crop-wise treatment requirements given in Table 2.

T. Aus rice

All the fertilizers and ½ of N fertilizer were applied as the basal dose during the final land preparation time (Table 2). The rest of N fertilizer was top-dressed at 30-40 days after seedling transplanting.

T. Aman rice

The full doses of P, S, Zn, and B fertilizers, ½ of K fertilizer, and 1/3rd of N fertilizer were broad casted during final land preparation. The rest of K fertilizer and another 1/3rd of N fertilizer were top-dressed at 20-25 days after seedling transplanting. The last 1/3rd of N fertilizer was top-dressed during the panicle initiation stage.

***Table 1.** Names of varieties, planting and harvesting times of T. Aus rice, T. Aman rice, sunflower, and sweet gourd in two cropping patterns (CP) at Sekendarkhali, Amtali, Barguna during 2019-2020 and 2020-21*

Crop	Variety	Planting time	Harvesting time
	CP_1		
T. *Aus* rice	Mala chyna (local) BRRI dhan48	15 June 2019 02-10 June 2020	28 August 2019 02 September 2020
T. *Aman* rice	BRRI dhan39 BRRI dhan49	10 September 2019 18 September 2020	11 December 2019 05 December 2020
Sunflower	BARI Surjomukhi-2	15-21 January 2020 08 January 2021	01-04 May 2020 08 April 2021
	CP_2		
T. *Aus* rice	BRRI dhan48	18 June 2019 02-10 June 2020	29 August 2019 04 September 2020
T. *Aman* rice	BRRI dhan39	08 September 2019 16 September 2020	10 December 2019 01 December 2020
Sweet gourd	Local Bengal sweet (Hybrid)	18-24 January 2020 27 December 2020	05-12 April 2020 13 April 2021

Sunflower

The full doses of all fertilizers and ½ of N fertilizer were broadcasted during the final land preparation. The rest of the N fertilizer was top-dressed at the bud initiation stage.

Sweet gourd

One-third of N, P, K, and S fertilizers, ½ of B fertilizer, and a full dose of Zn fertilizer were mixed with soil and equally applied in each of the pits as the basal doses after the final land preparation. One-third of N and K fertilizers were applied around each plant in each pit at 20-25 days after planting. The rest 1/3rd of N and K fertilizers, 1/3rd of P and S fertilizers, and ½ of B fertilizer were applied around each pit at 50-55 days after planting.

Data collection

The field data were collected on plant height, yield, and yield contributing characters of all the crops of both patterns at their harvest. Rice crops were harvested at maturity when 80% of the grains became golden in colour. Grain yields from each plot were recorded individually and then adjusted to 14% moisture content. The heads of sunflower were cut from the plants and dried on the threshing floor for about 6-7 days to record seed yield individually from each plot. Then the seed yield of sunflower was finally adjusted to 8% moisture content.

Analysis of soil and plants

The initial soil samples were collected from the study fields at 0-20 cm depth before starting the experiments. The laboratory analysis was done for both initial soil samples and post-harvest soil after the completion of two years of the study. The grain and straw of *Aus* and *Aman* rice were sampled and analyzed in the laboratory for plant nutrient (N,P, K, and S) analysis (Cataldo *et al.,* 1974; Jackson, 1973; Wilde *et al.,* 1979). The leaf, petiole stem, and head of the sunflower and fruit and vine of sweet gourd were subjected to laboratory analysis.

Soil pH was determined by electrode method and Total N was measured by micro-Kjeldhal digestion and distillation method (Jackson, 1973). The available P of soil was determined using Bray and Kurtz (1945) method. The exchangeable K was extracted following the method of Knudsen *et al.* (1982) and soil available S was measured by the method of Hunt (1980).

At the maturity stage of sunflower, 15 plants from

Table 2. *Treatment-wise applied nutrient elements for T. Aus rice-T. Aman rice-sunflower (CP$_1$) and T. Aus rice-T. Aman rice-sweet gourd (CP$_2$) cropping patterns*

Treatment	N-P-K-S-Zn (kg ha^{-1} year^{-1}) added to T. *Aus* rice	N-P-K-S-Zn-B (kg ha^{-1} year^{-1}) added to T. *Aman* rice	N-P-K-S-B (kg ha^{-1} year^{-1}) added to sunflower
CP$_1$			
NM$_1$	80-14-43-7-2	84-16.5-43-10-2-1.7	128-46-101-32-2
NM$_2$	100-14-53-7-2	105-16.5-54-10-2-1.7	160-46-126-32-2
NM$_3$	99-15-61-4.3-2	85-15-71-12.4-2-1.7	123-43-81-29-2
NM$_4$	87-12-51-7-2	90-10-5-11-2-1.7	-
NM$_5$	60-19-20-8-2	83-23-45-9-2-1.7	92-34-80-28-2
CP$_2$			
NM$_1$	82-13-43-6-2	78-14-44-6.7-2-1.7	98-43-40.5-16.6-2
NM$_2$	102-13-54-6-2	98-14-55-6.7-2-1.7	122.1-43.6-50.5-16.7-2
NM$_3$	99-15-61-4.32-2	84-15-71-12-2-1.7	88-42.6-70.5-28.1-2
NM$_4$	87-12-51-7-2	90-10-50-11-2-1.7	75-36-45-13.5-2
NM$_5$	60-19-20-8-2	83-25-45-9-2-1.7	115-56-110-18-2

CP$_1$: T. *Aus* rice-T. *Aman* rice-Sunflower, CP$_2$: T. *Aus* rice-T. *Aman* rice-Sweet gourd, NM$_1$: Soil test-based fertilizer dose, NM$_2$: Soil test-based fertilizer dose + 25% NK, NM$_3$: Fertilizer dose as per FRG-2018, NM$_4$: BAU soil testing kit-based fertilizer dose, and NM$_5$: Farmer's applied fertilizer dose

each plot were sampled to determine N, P, K, and S content. The above-ground plant parts were cut into small pieces and then dried in the oven at 70°C to a constant weight. The oven-dried plant samples were ground finely to estimate the total N concentration by the modified Kjeldahl digestion colorimetric method (Cataldo *et al.,* 1974). For P and K determination, plant materials were digested in tri-acid (HNO_3: H_2SO_4: $HClO_4$::10:1:4) (Jackson, 1973; Wilde *et al.,* 1979) and estimated by spectrophotometer and flame photometer, respectively. The turbidmetric method estimated the S concentration using barium chloride and gum acacia (Chesnin and Yien, 1951).

In the case of sweet gourd, the vine and fruit samples were collected from each plot at harvest and washed under tap water, then 0.1 N HCl followed by distilled water and finally with the double distilled water. The samples were then air dried and oven dried at 68°C (Jackson, 1973). Then the samples were ground and the required quantity of sample was weighed accurately on an electronic balance and used for further analysis of nitrogen (Micro-Kjeldhal method), phosphorus (Vanadomolybadate phosphoric yellow colour method), potassium (flame photometric method) and sulphur (Jackson, 1973).

Calculation of plant nutrient uptake

The uptakes of nutrients (N, P, K, and S) by *Aus* and *Aman* rice, sunflower, and sweet gourd were estimated by multiplying the dry matter yield (after sun drying to constant weight) of each crop with their corresponding nutrient concentration.

Apparent nutrient balance

Cropping pattern-based apparent nutrient balance was estimated by subtracting the amount of nutrients removed by crops from the amount of added nutrients in each crop of the pattern through organic and inorganic fertilizers.

Statistical analysis

The collected data were subjected to a two-way analysis of variance (ANOVA) for years and treatments using the open-source software R (version 3.3.3). The means were separated based on the least significant difference (LSD) test at a 5% level of significance.

Economic analysis

The economic analysis was done on the productivity of *Aus* rice, *Aman* rice and sunflower/ sweet gourd in CP_1 and CP_2 based on *Aman* rice equivalent yield (REY). REY was calculated by using the following Eq. 1 (Ahlawat and Sharma, 1993).

The price of organic and inorganic fertilizers along with the costs of seeds, labour, pesticides, irrigation, and some other factors were considered as the total variable cost. The farm gate prices of products were collected from local farmers and markets to compute gross return and gross margin. Marginal benefit-cost ratio (MBCR) was calculated by the following Eq. 2.

$$\text{REY}= \frac{\text{Yield of each crop (t ha}^{-1}\text{)} \times \text{Price of the crop (Taka t}^{-1}\text{)}}{\text{Price of rice (Taka t}^{-1}\text{)}} \quad \ldots (1)$$

$$\text{MBCR}= \frac{\text{Gross Return (Treatment)} - \text{Gross Return (Control)}}{\text{Variable Cost (Treatment)} - \text{Variable Return (Control)}} \quad \ldots (2)$$

RESULTS AND DISCUSSION

Soil analysis

The soil was clay loam in texture and acidic in nature and had low organic matter (Table 3). Both the study fields were non-saline during the establishment period of T. *Aus* rice in 2019. The initial soils of both fields were very poor in nitrogen and phosphorus, poor in sulfur and rich in zinc, while K and B were at optimum levels. Haque *et al.* (2023) also reported that coastal soils are deficient in N and P.

After completion of the two-year cropping cycle, the post-harvest soils were more acidic in nature, and salinity levels were at the peak. This happened because the post-harvest soil samples were collected after the harvest of sunflower and sweet gourd in June 2021 when the soil salinity levels were high.

Crop productivity

A two-year cropping cycle of CP_1 and CP_2 showed that component crop yields of the patterns significantly varied with nutrient management treatments (Table 4). The yields of ausand *aman* rice and the system productivity of CP_1 significantly varied with the year. For CP_2, yields of *Aus* rice and sweet gourd, and the system productivity significantly varied with years. The interaction effects of year and nutrient management on the yields of component crops and the system productivity for both patterns were non-significant except for the fruit yield of sweet gourd. The coastal zone is mainly characterized by water logged saline soils with heavy rainfall in the monsoon (*Aman*) season and a shallow water table (Mainuddin *et al.,* 2021) which are serious threats to coastal agriculture (Barrett-Lennard, 2003; Falakboland *et al.,* 2017). The variability in the amount or pattern of monsoon rainfall over the year influence the intensity of salinity and water logged conditions. Delayed sowing of *Rabi* (dry season) crops due to water logging after harvest of *Aman* rice caused yield loss of *Rabi* crops (Paul *et al.,* 2020). Therefore, the economy of the farmers of the coastal zone has until now been highly dependent on *Aman* rice-based mono-culture productivity.

The highest *Aus* rice yield was recorded in 2020-21 and the highest *Aman* rice yield was in 2019-20 (Table 5 and Table 6). Application of soil test-based (STB) fertilizer dose plus 25% NK provided the highest grain yields of *Aus* and *Aman* rice, seed yield of sunflower, and fruit yield of sweet gourd, and also offered the highest system productivity for both cropping patterns. Therefore, blanket fertilizer recommendations for crops especially for *Aman* rice and *Rabi* crops despite a range of soil conditions and land types might not be useful to achieve satisfactory yields (Mainuddin *et al.,* 2019; Sarkar *et al.,* 2022).

Table 3. *Initial and post-harvest properties of soil at 0-20 cm depth of the field with T. Aus-T. Aman rice-sunflower cropping pattern (CP_1) and T. Aus rice-T. Aman rice-sweet gourd cropping pattern (CP_2) at Sekendarkhali, Amtali, Barguna during 2019 and 2021*

Soil	pH	EC (dS m^{-1})	OM (%)	Total N (%)	P (µg g^{-1} soil)	K (meq.100 g^{-1} soil)	S (µg g^{-1} soil)	Zn (µg g^{-1} soil)	B (µg g^{-1} soil)
CP_1									
Initial	6.6	0.49	1.63	0.093	2.70	0.28	14.0	2.26	0.54
Interpretation	acidic	Non-saline	L	VL	VL	Opt	L	H	Opt
Post-harvest	4.5	8.27	2.27	0.11	2.25	0.52	23.7	2.47	0.39
Interpretation	acidic	saline	L	L	VL	VH	M	VH	M
CP_2									
Initial	6.4	0.38	1.87	0.081	2.90	0.23	15.0	2.17	0.49
Interpretation	acidic	Non-saline	L	VL	VL	Opt	L	H	Opt
Post-harvest	5.21	7.22	1.62	0.08	4.14	0.40	18.24	2.36	0.61
Interpretation	acidic	saline	L	VL	VL	VH	M	VH	H

Here, 'VL' denotes "Very low', 'L' denotes 'Low', 'Opt' denotes 'Optimum', 'H' denotes 'High' and 'VH' denotes 'Very high'

Table 4. *Effect of nutrient management and year on grain yields of T. Aus rice and T. Aman rice, seed yield of sunflower, fruit yield of sweet gourd, and the system productivity of T. Aus rice-T. Aman rice-Sunflower (CP_1) and T. Aus rice-T. Aman rice-Sweet gourd (CP_2) cropping patterns at Sekendarkhali, Amtali, Barguna*

Treatments	Grain yield		Seed yield	System productivity
CP_1				
	T. *Aus* rice	T. *Aman* rice	Sunflower	
Year (Y)	***	***	NS	**
Nutrient management (NM)	***	*	***	***
Y×NM	NS	NS	NS	NS
CP_2				
Year (Y)	***	NS	***	***
Nutrient management (NM)	***	**	***	***
Y×NM	NS	NS	*	NS

NS = Non-significant; * = Significant at 5%; ** = Significant at 1%; *** = Significant at 0.1%

Additional NK with STB fertilizer dose increased the system productivity of CP_1 by 31% and 29% in CP_2 compared to the farmers' applied dose. The coastal soil of the study area is very much deficient in N (Table 3). The additional application of N and K with the recommended STB fertilizer dose might influence biomass production with increasing robustness of the crop plants that contributed to producing high yields. Improvement in crop yields by site-specific plant nutrients has been reported in several earlier studies (Dobermann *et al.,* 2013; Rafique *et al.,* 2012; Timsina *et al.,* 2006). Das *et al.* (2018) also reported an increase in yield of the component crops of the wheat-maize-rice cropping pattern by the application of 25% NK with STB fertilizer dose that ultimately influenced the system productivity in terms of wheat equivalent yield; however, the study was done in high Ganges River floodplain area.

Economic analysis

The cost and return analysis results showed that STB fertilizer dose plus 25% NK application offered maximum gross return, gross margin, and the highest benefit-cost ratio (BCR) for both patterns (Table 7). Additional application of NK with STB fertilizer dose ensured more gross margin by Tk. 50472 for CP_1 and Tk. 137635 for CP_2 on average compared to the farmers' applied fertilizer dose. Earlier studies also supported our finding that additional application of fertilizers with soil test-based fertilizer dose influenced enhanced productivity and economic profitability as well in other cropping systems in the high Gages River floodplain or Northern region of Bangladesh (Hossain *et al.,* 2016a; Jahan *et al.,* 2016). Interestingly, the study also pointed out that the profitability of CP_2 was more than CP_1 and this was attributed to the high selling price for sweet gourd compared to the sunflower. In another study done at Amtali, Barguna, Saha *et al.* (2019) marked out that the improved cropping pattern like T. *aman* rice-potato-mungbean-T. *aus* rice cropping pattern could be profitable in salt-affected coastal zones of Bangladesh with judicious application of irrigation from comparatively low salinity content surface water.

Table 5. *Grain yields (t ha^{-1}) of T. Aus rice and T. Aman rice, seed yield (t ha^{-1}) of sunflower, and system productivity in terms of Aman rice equivalent yield of T. Aus rice-T. Aman rice-sunflower cropping pattern at Sekendarkhali, Amtali, Barguna*

Treatments	T. *Aus* rice	T. *Aman* rice	Sunflower	System yield (REY)
Year				
Y_1 (2019-20)	2.80b	3.62a	1.82a	11.42a
Y_2 (2020-21)	3.42a	3.20b	1.84a	10.68b
Nutrient management (NM)				
NM_1	2.85cd	3.27b	1.81b	11.72b
NM_2	3.72a	3.60a	2.22a	14.15a
NM_3	3.25b	3.38ab	1.74bc	12.01b
NM_4	2.98c	3.56a	-	6.54d
NM_5	2.76d	3.25b	1.55c	10.81c

Here, NM_1 = soil test-based fertilizer dose, NM_2 = soil test-based fertilizer dose plus 25% NK, NM_3 =BAU soil testing kit-based fertilizer dose, NM_4 = fertilizer dose based on FRG-2018, NM5 = Farmer's applied fertilizer dose; Output price (Tk. kg^{-1}): T. *Aus* and T. *Aman* rice: 16 for 2019-20; T. *Aus* and T. *Aman* rice: 20 for 2020-21; Sunflower: 55 for both years; 1 US$ = 109 Bangladeshi Taka; In a column, figures followed by same letters do not vary significantly

Nutrient uptake

The analysis results revealed that plant N, P, K, and S uptake in CP_1 ranged from 242.5 to 655.4, 112.0 to 197.0, 255.5 to 429.7, and 73.5 to 127.3 kg ha^{-1}, respectively (Fig. 4). In CP_2, N, P, K, and S uptake ranged from 550.5 to 661.5, 139 to 182.0, 375.6 to 465.6, and 64.8 to 79.5 kg ha^{-1}, respectively (Fig. 5). In CP_1, plants with STB

Table 6. *Grain yields (t ha^{-1}) of T. Aus rice and T. Aman rice, fruit yield (t ha^{-1}) of sweet gourd, and system productivity in terms of Aman rice equivalent yield of T. Aus rice-T. Aman rice-sweet gourd cropping pattern at Sekendarkhali, Amtali, Barguna*

Treatments	T. *Aus* rice	T. *Aman* rice	Sweet gourd	Rice equivalent yield (REY)
Year				
Y$_1$ (2019-20)	2.94b	3.46a	31.87a	36.27a
Y$_2$ (2020-21)	3.54a	3.48a	23.02b	32.92b
Nutrient management (NM)				
NM$_1$	2.91bc	3.32b	24.34c	31.00c
NM$_2$	3.79a	3.58a	32.23a	39.93a
NM$_3$	3.61a	3.51a	27.83b	35.39b
NM$_4$	3.06b	3.62a	28.48b	35.66b
NM$_5$	2.83c	3.33b	24.34c	31.01c

Here, NM$_1$ = soil test-based fertilizer dose, NM$_2$ = soil test-based fertilizer dose plus 25% NK, NM3 = BAU soil testing kit-based fertilizer dose, NM$_4$ = fertilizer dose based on FRG - 2018, NM$_5$ = Farmer's applied fertilizer dose; Output price (Tk. kg^{-1}): T. *Aus* and T. *Aman* rice: 16 and sweet gourd: 15 for 2019-20; T. *Aus* and T. *Aman* rice: 20 and sweet gourd: 22.5 for 2020-21; 1 US$ = 109 Bangladeshi Taka; In a column, figures followed by same letters do not vary significantly

Table 7. *Economic analysis of T. Aus rice-T. Aman rice-Sunflower (CP$_1$) and T. Aus rice-T. Aman rice-sweet gourd (CP$_2$) cropping patterns at Sekendarkhali, Amtali, Barguna during 2019-20 and 2020-21*

Treatments	Bangladesh Taka per hectare							
	CP$_1$				CP$_2$			
	Gross return	Total variable cost	Gross margin	MBCR	Gross return	Total variable cost	Gross margin	MBCR
2019-20								
NM$_1$	195200	183650	11550	3.98	510987	325810	185177	7.27
NM$_2$	230720	188104	42616	6.25	705600	334350	371250	19.89
NM$_3$	201440	183822	17618	5.54	596000	330350	265650	15.27
NM$_4$	104160	108450	-4290	1.08	592640	329250	263390	17.76
NM$_5$	181760	180271	1489	-	496747	323850	172897	-
2020-21								
NM$_1$	224800	182775	42025	3.13	481120	325760	275640	-2.66
NM$_2$	277600	189104	88496	5.75	572000	337750	377317	5.10
NM$_3$	228400	184272	44128	2.99	536640	334500	336233	3.31
NM$_4$	131600	106100	25500	1.05	548320	333600	351800	4.52
NM$_5$	205200	176521	28679	-	495520	319000	300400	-

Here, NM$_1$ = Soil test-based fertilizer dose, NM$_2$ = Soil test-based fertilizer dose plus 25% NK, NM$_3$ = BAU soil testing kit-based fertilizer dose, NM$_4$ = fertilizer dose based on FRG-2018, NM$_5$ = Farmers' applied fertilizer dose; Input price (Tk. kg-1): Sweet gourd seed = Tk. 260, Urea = Tk. 16, TSP = Tk. 22, MoP = Tk. 15, Gypsum = Tk. 12; *T. *Aman* rice equivalent yield; Output price (Tk./kg): T. *Aus* and T. *Aman* rice: 16, Sweet gourd: 15 for 2019-20; T. *Aus* and T. *Aman* rice: 20, Sweet gourd: 22.5 for 2020-21; Sunflower: 55 for both years; 1 US$ = 109 Bangladeshi Taka

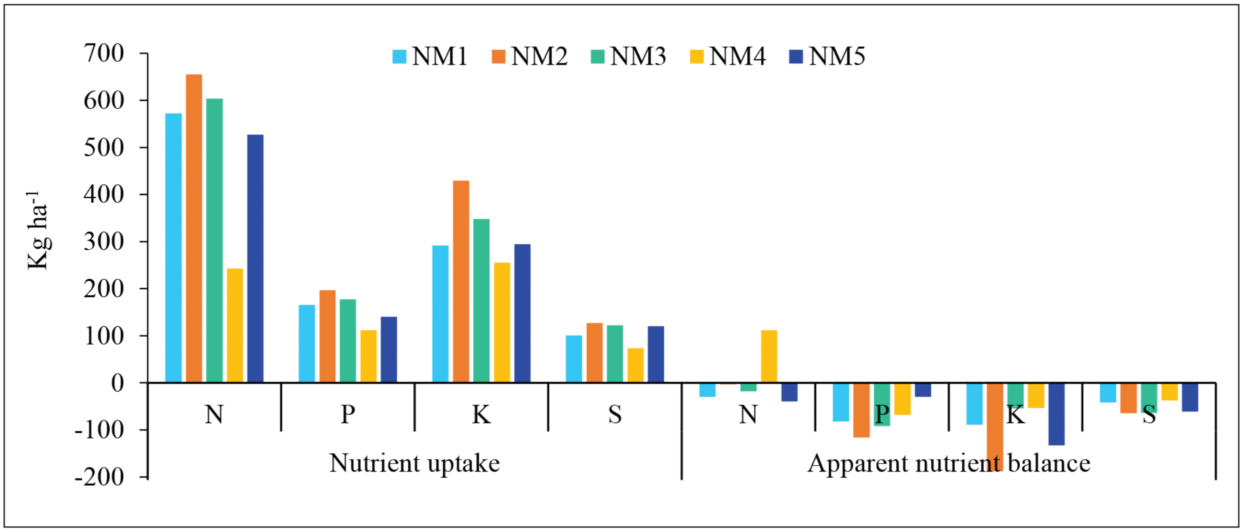

Fig. 4. *Total nutrient uptake and apparent nutrient balance in T. Aus - T. Aman rice - sunflower cropping pattern at Amtali, Barguna during 2019-2021*

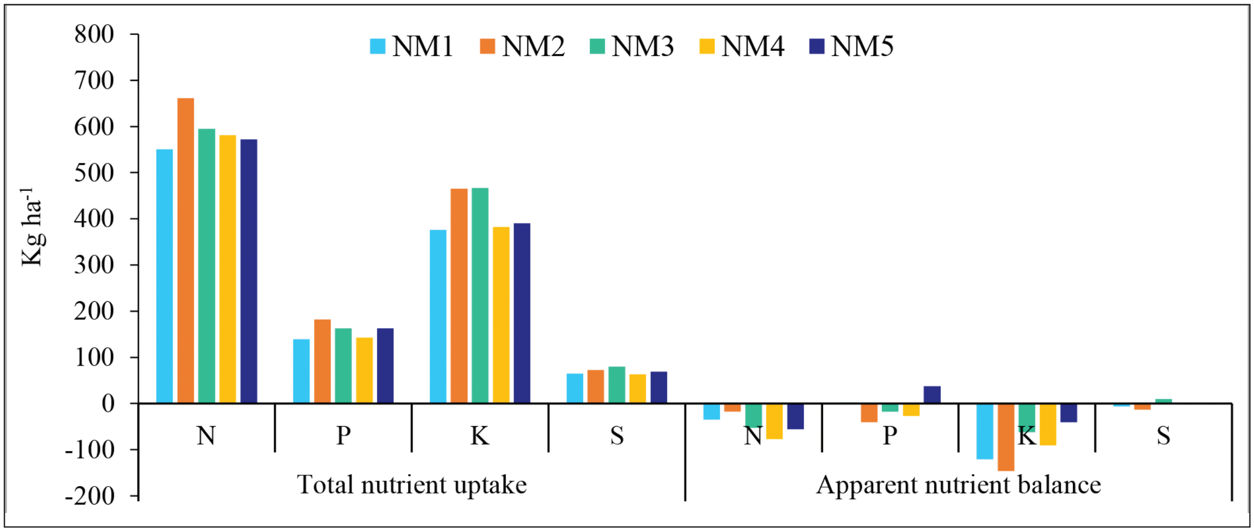

Fig. 5. *Uptake and apparent nutrient balance of N, P, K, and S in T. Aus-T. Aman rice-sweet gourd cropping pattern at Amtali, Barguna during 2019-2021*

fertilizer dose plus NK had greater uptakes of N, P, K, and S; whereas, N and P uptakes were greater in STB fertilizer plus 25% NK for CP_2 and, K and S uptakes were greater for BAU soil testing kit-based applied fertilizer dose (Fig. 5).These results of nutrient uptake were mostly associated with the greater uptake by sunflower and even sweet gourd compared to the rice crops. Panaullah *et al.* (2006) and Saleque *et al.* (2006) reported greater uptake of nutrients in three crop-based cropping patterns that required more nutrients compared to the monocrop culture.

Apparent nutrient balance

The apparent nutrient balance results clearly showed negative trends in all the treatments for CP_1 except BAU soil testing kit-based fertilizer dose treatment (Fig. 4). The apparent nutrient balance for N, P, K, and S in CP_1 ranged from - 39.2 to 111.5, - 115.7 to - 29.9, - 188.1 to - 53.5, and - 64.6 to - 37.5 kg ha^{-1}, respectively. The apparent N, P, K, and S balance in CP_2 ranged from -76.9 to - 17.3, - 40.8 to 1.79, -146.6 to - 40.5, and -13.5 to 9.3 kg ha^{-1}, respectively (Fig. 5). The maximum negative apparent N balance in CP_1 was observed in the farmers' applied fertilizer dose-treated plots and from FRG-based fertilizer dose-treated plots in CP_2. For P, K, and S, STB fertilizer dose plus 25% NK treated plots had the maximum magnitude of negative apparent balance in both patterns. This can be attributed to higher yield and nutrient uptake by the intensive rice-rice-sunflower or rice-rice-sweet gourd patterns.

According to FAO (2022), nutrient surpluses are a threat to environmental quality mainly to water and air quality. On the contrary, nutrient deficits are indications of soil nutrient mining with potential deterioration of soil health over time. Some earlier studies reported the negative magnitude of N balance (Hossain *et al.,* 2016b; Jahanet al., 2019) and other nutrient balances (Chauhan *et al.,* 2012; Singh *et al.,* 2005) could be reduced by incorporating crop residues in the soil. Previous crop residue especially rice straw residue can help to refill the extensive uptake nutrients to the soil.

CONCLUSION

The challenge of improving the productivity of the coastal region could be faced by intensifying cropping including sunflower or sweet gourd in the rice-based cropping system. The study identified rice-rice-sweet gourd pattern was more profitable than the rice-rice-sunflower pattern for the coastal region. The productivity of both patterns can be maximized through soil test-based fertilizer dose plus 25% NK which also helped the coastal farmers to have the maximum economic profit. However, the negative apparent nutrient balance trend for both patterns indicate a requirement for more nutrient supply to the coastal soil.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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