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Integrated Rice-Based Shrimp and Crabs Farming: Adaptation to Climate Change and Potential Mitigation of Global Warming in the Coastal Wetlands of Bangladesh

Muhammad Aslam Ali[1*], Shahroz Mahean Haque[2], Khalid Sohrawardi[1], S. K. Fazlay Rabbi[1], Shuvo Kumar Sarkar[1], Hafsa Jahan Hiya[1], Fakir Azmol Huda[3], Sumon Malakar[4], Mahjabeen Rahman[5], Md. Shakir Ahammed[1]

[1]Department of Environmental Science, Bangladesh Agricultural University, Mymensingh, Bangladesh
[2]Department of Fisheries Management, Bangladesh Agricultural University, Mymensingh, Bangladesh
[3]Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh, Bangladesh
[4]Caritas Bangladesh, Satkhira, Bangladesh
[5]Department of Environmental Sciences, Rutgers, The State University of New Jersey, New Brunswick, USA
Email: *aslam.envs@bau.edu.bd, Shahrozmhaque.fm@bau.edu.bd, khalidrokons@gmail.com, fazlayrabbiag22@gmail.com, sarkarshuvo.just@gmail.com, hafsa_envsc@bau.edu.bd, fahuda@bau.edu.bd, sumankumarmalaker@gmail.com, mahjabeen.rahman@rutgers.edu, shakiresrm@gmail.com

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Abstract

Coastal agriculture is vulnerable to climate change, thereby may affect food production systems and food security in Bangladesh. Methane (CH_4) emission from coastal wetlands rice farming is a major environmental concern due to its global warming potential. Therefore, field experiments were conducted at the southern coastal region of Shyamnagar, Satkhira, to investigate the feasibility of Rice-Shrimp and Rice-Crabs mixed farming for adaptation to the changing climate and sustaining food production system. The experimental treatments were designed on rice-based diversified farming systems such as rice sole cropping with no NPKS + no soil amendments (T1), rice sole cropping following farmers' practice (FP) without soil amendment (T2), rice sole cropping following FP with phosphogypsum (PG) amendment (T3), Rice-Shrimp mixed culture with PG amendment (T4), Rice-Crabs mixed culture with PG amendment (T5), Rice-Shrimp mixed culture + PG amendment with Spirulina (Cyanobacteria) inoculation (T6), and Rice-Crabs mixed culture + PG amendment with Spirulina inoculation (T7). A closed chamber technique was followed to collect gas samples from the rice paddy field and samples were analyzed by Gas Chromatograph. It was found that Rice-Shrimp (T6) and Rice-Crabs mixed farming (T7) practices significantly decreased GWPs compared to the rice sole cropping system. In the dry boro season, the maximum GWPs 4175 kg CO_2 eq. ha^{-1} was recorded from rice sole cropping (T2), which was decreased by 30% and 36.7% under Rice-Shrimp (T6) and Rice-Crabs (T7) mixed farming practices, respectively. Furthermore, in the wet aman season, maximum GWP 4525 kg CO_2 eq. ha^{-1} was recorded from rice sole cropping (T2), which was decreased by 33.0% and 38.8% under Rice-Shrimp and Rice-Crabs mixed farming, respectively. Rice grain yield was low under rice sole cropping (3500 kg/ha), which was increased by 11.0% and 14.7% under Rice-Shrimp mixed farming amended with PG and Spirulina (T6) during wet aman and dry boro seasons, respectively. The postharvest soil properties, such as soil organic matter content, redox potential value (Eh), and exchangeable K^+ and Ca^{2+}, contents in soil increased significantly with Phosphogypsum and Spirulina applications, however, decreased Na^+ content and electrical conductivity (EC) eventually improved rice plants' tolerance to salinity and enhanced overall productivity of Rice-Shrimp and Rice-Crabs mixed farming. Conclusively, the conversion of wetland mono rice cropping into mixed Rice-Shrimp and Rice-Crabs farming would be a feasible strategy to sustain rice aquaculture-based farming, ensure food security and mitigate GWPs in coastal wetlands ecosystem.

Keywords

Coastal Paddy, Shrimp, Crabs, Spirulina, GWPs

1. Introduction

Bangladesh is situated in the northeastern part of South Asia between 20˚34'N and 26˚38'N latitude and 88˚01'E and 92˚41'E longitude. The coastal agriculture of Bangladesh is highly vulnerable to climate change. Climate change-induced coastal inundation, flooding, and soil salinity hampered farm productivity and decreased the cultivable crop area over the past decade [1]. Sea level rise and saltwater intrusion have been pushing agricultural production systems at risk, thereby decreasing coastal agricultural production efficiency in Bangladesh [2]. Many farmers have switched to raising tiger shrimp in shallow ponds, the second biggest export item after garments. However, the shrimp are now dying in many areas, probably due to viral infections. In regards to this situation, the conversion of shrimp farming towards rice-fish (shrimp) crabs mixed farming could be a feasible strategy for sustainable agricultural production and adaptations to climate change. The rice-fish crabs farming will provide rice to the resource-poor farmers as the main crop and subsidiary products such as fish protein from the same piece of land at the same time. Besides, shallow water fish and crabs' movement in paddy fields may suppress CH_4 emissions and improve salinity [3]. In Bangladesh, shrimp culture is mostly practiced in brackish, saline and freshwater of the coastal areas of Khulna, Satkhira, Bagerhat and Cox's Bazar districts.

The shrimp farming has expanded widely, thereby contributing greatly to the national economy of the country, which is approximately 1.7% of the value of Bangladesh exports [4]. However, shrimp farming adversely affected the coastal ecology of Bangladesh through deterioration of soil quality due to increased salinity levels, a decrease in the local variety of fish and shellfish, local water pollution and change in local hydrology and depletion of mangrove forest cover [5]. Groundwater salinization and saline water intrusion in surrounding areas have caused serious ecological and socioeconomic damage to the coastal environment. Soil salinity may also influence CH_4 emission from wetland rice fields [6], which is a great concern in salt-affected coastal areas of Bangladesh, especially during the boro season. Therefore, coastal rice cropping systems have to be modified towards diversified farming systems for strengthening food security and mitigation of methane emissions. Rice fields are an important source of natural food and shelter for shrimp prawns/fishes/crabs, which may effectively utilize the available land and water resources. Integration of shrimps/prawns and fish in rice fields is a feasible means to sustainable intensification of agriculture, producing more food from the same area of land without worsening environmental impacts [7] [8]. The integrated approach of rice-fish and Rice-Crabs farming may effectively utilize the potentiality of rice cultivars, crabs and fishes in wetlands for increasing farm productivity without dependence on high-cost modern inputs. The strength of CH_4 fluxes may be affected by the inputs utilized and the movement of fishes/crabs in the wetland paddy field ecosystem. Nowadays, shrimp farmers are shifting towards crabs farming due to its less susceptibility to diseases, easier to culture, more resistance to adverse environmental conditions and good market value both locally and internationally [9]. Brackish water crab culture near the riverbanks in the tidal zone around the Sundarban area may change the farmers' socioeconomic status [10].

Sustaining agricultural productivity in the coastal wetlands and ameliorating the salinity stress as well as improving ecosystem diversified cropping systems such as integrated Rice-Shrimp crabs farming, soil amendments with combined application of organic, inorganic and biological agents such as Spirulina (BGA) may be an effective option [11]. BGA cyanobacteria are important biotic components of the wetland paddy ecosystem.

Recently, it has been reported that the application of phospho-gypsum with Azolla-cyanobacteria inoculation in rice paddy fields improved the soil redox potential status, enhanced CH_4 oxidation and eventually decreased CH_4 emission [12] [13]. The use of blue-green algae Spirulina in aquaculture has been reported beneficial for fish culture. Spirulina contains high amounts of vitamins, minerals and protein for animal feed. So, spirulina may be used as an alternative protein source in fish feed, which will enhance the survival and growth rates of fish. Furthermore, it has been reported that Spirulina inclusion in fish diets significantly amended the hazard of lead toxicity [14].

Although greenhouse gas flux measurements have been extensively taken in natural wetlands and rice paddies, field measurements were rarely taken in rice-based intensive managed aquaculture wetlands. There are no specific research findings available so far in regard to methane emissions as well as GWPs under Rice-Shrimp and Rice-Crabs farming in the coastal wetlands of Bangladesh. Therefore, this research programme has undertaken to investigate the utilization of feasible soil amendments to reduce global warming potentials for Rice-Shrimp and Rice-Crabs mixed farming and sustaining agricultural productivity in coastal wetlands of Bangladesh.

2. Materials and Methods

2.1. Experimental Location, Treatments, Design and Field Preparation

The experimental field is located at 22˚66'79" North latitude and 89˚10'89" East longitude at an elevation of 11 m above the sea level, which covers High Ganges river floodplain and Ganges Tidal Floodplain (AEZ 11 and AEZ 13). The soil of the experimental land belongs to the Satla and Harta soil series of dark grey soil. Finally, field experiments were undertaken at the suitable location of the selected Shyamnagar Upazilla from October 2020 to November 2021. BRRI Dhan 67 was cultivated in boro season, while BRRI Dhan 73 was cultivated in aman season. The Experimental Treatments were T1: Rice sole cropping no NPKS, no organic soil amendments, T2: Rice sole cropping following farmers' practice (100% NPKS) with no soil amendment, T3: Rice sole cropping (100% NPKS) with Phosphogypsum (PG) amendments, T4: Rice-Shrimp mixed culture with PG amendments, T5: Rice-Crabs ($10/m^2$) mixed culture with PG amendments, T6: Rice-Shrimp mixed culture + PG amendments with Spirulina (Cyanobacteria) inoculation, T7: Rice-Crabs ($10/m^2$) mixed culture + PG amendments with Spirulina (Cyanobacteria) inoculation. The experiment was setup with randomized complete block design (RCBD) along with three replications. The experimental plots were kept under 10 cm water levels and the surrounding trench was kept 25 cm deep as per requirement.

2.2. Gas Sampling and Analysis

Gas samples were collected through closed-chamber method from the rice paddies and Rice-Shrimp, Rice-Crabs farming wetlands. Gas samplings were carried out once a week. Acrylic glass chamber was placed in each plot. Four holes at the bottom of each chamber were kept to facilitate water movement. The air gas samples from the transparent glass chamber (Diameter 62 cm, and height 112 cm) were collected by using 50 ml gas-tight syringes at 0, 15 and 30 minutes intervals after chamber placement over the rice planted plots. CH_4 concentrations in the collected air samples were measured by Gas Chromatography (Shimadzu, GC-2014, Japan) packed with Porapak NQ column (Q 80 - 100 mesh) and a flame ionization detector (FID). A closed-chamber equation [15] (Rolston, 1986) was used to estimate methane fluxes for every treatment.

$$F = \rho \times V/A \times \Delta c/\Delta t \times 273/T$$

where, F (Flux) = CH_4 emission rate (mg CH_4 m^{-2} hr^{-1}), ρ = gas density (0.714 $mg \cdot cm^{-3}$), V = volume of chamber ($A \times h$; m^3), A = surface area of chamber (length × width; m^2), h = height of the chamber (m), $\Delta c/\Delta t$ = rate of increase of CH_4 gas concentration ($mg \cdot m^{-3} \cdot hr^{-1}$), T (absolute temperature) = 273 + mean temperature (˚C). Total methane flux for the entire cropping period were computed by the formula: Total CH_4 flux $= \sum_{i=1}^{n} \left(Ri \times Di \right)$, where, Ri = rate of methane flux ($g \cdot m^{-2} \cdot d^{-1}$) in the ith sampling interval, and n = number of sampling intervals [16].

2.3. Estimation of GWP

To estimate the GWP, CO_2 is typically taken as the reference gas, and an increase or reduction in emission of CH_4 is converted into "CO_2-equivalents" by means of their GWPs. In this study, we used the IPCC factors to calculate the combined GWP for 100 years (GWP = 25 × CH_4, kg CO_2-equivalents ha^{-1}) from CH_4 under various agricultural irrigation practices [17].

2.4. Soil and Water Properties Analysis

Soil redox potential (Eh), flood water pH, EC, dissolved iron and dissolved oxygen (DO) concentrations were measured at every week interval during rice cultivation. Organic carbon was determined volumetrically by wet oxidation method [18] and the organic matter content was calculated by multiplying the percent organic carbon with the Van Bemmelen factor of 1.73. Total nitrogen content in soil was determined by Micro-Kjeldahl method [19]. Digestion was made with conc. H_2SO_4 and catalyst mixture (K_2SO_4:$CuSO_4 \cdot 5H_2O$: soil in the ratio of 100:10:1). Total-Nitrogen in the digest was estimated by distillation with 40% NaOH followed by titration of distillate trapped in H_3BO_3 with 0.01 N H_2SO_4. Exchangeable calcium (Ca), sodium (Na) and potassium (K) were extracted from soil using 1M CH_3COONH_4 solution and their concentrations in the extract were directly determined by Flame photometer (FP 902-5 PG Instrument). For analyzing ammonium and nitrate in water samples, the samples were filtered with 0.45 µm filter papers. Ammonium (NH_4^+) concentration in water samples were determined by Indophenol blue method: a sample volume of 25 ml was transferred into a 50-ml Erlenmeyer flask, then 1 ml phenol solution, 1 ml sodium nitroprusside solution and 2.5 ml oxidizing solution were added with thorough mixing after each addition. The samples were covered with parafilm and kept in the dark at room temperature for at least 1 h. The absorbance was measured at 640 nmusing a UV spectrophotometer (UV-VI Mini 1240, Shimadzu Corporation, and Kyoto, Japan). NO_3^- concentration in water samples was determined at 410 nm using a UV Spectrophotometer. Ferrous iron concentrations in fresh soil samples were determined by 2M Na-acetate extraction method and water soluble iron by 1, 10-Phenanthroline method [20].

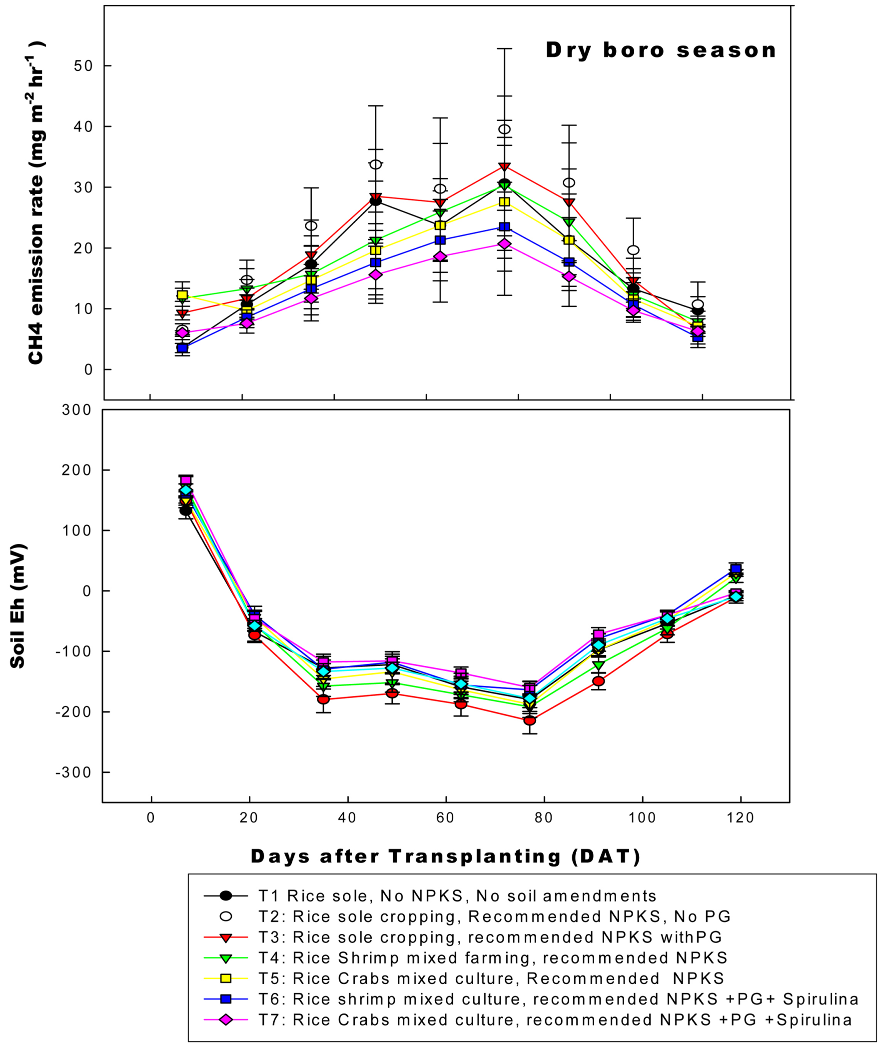
3. Results

3.1. CH_4 Emission Rate and Soil Redox Status during Rice-Shrimp and Rice-Crabs Mixed Farming

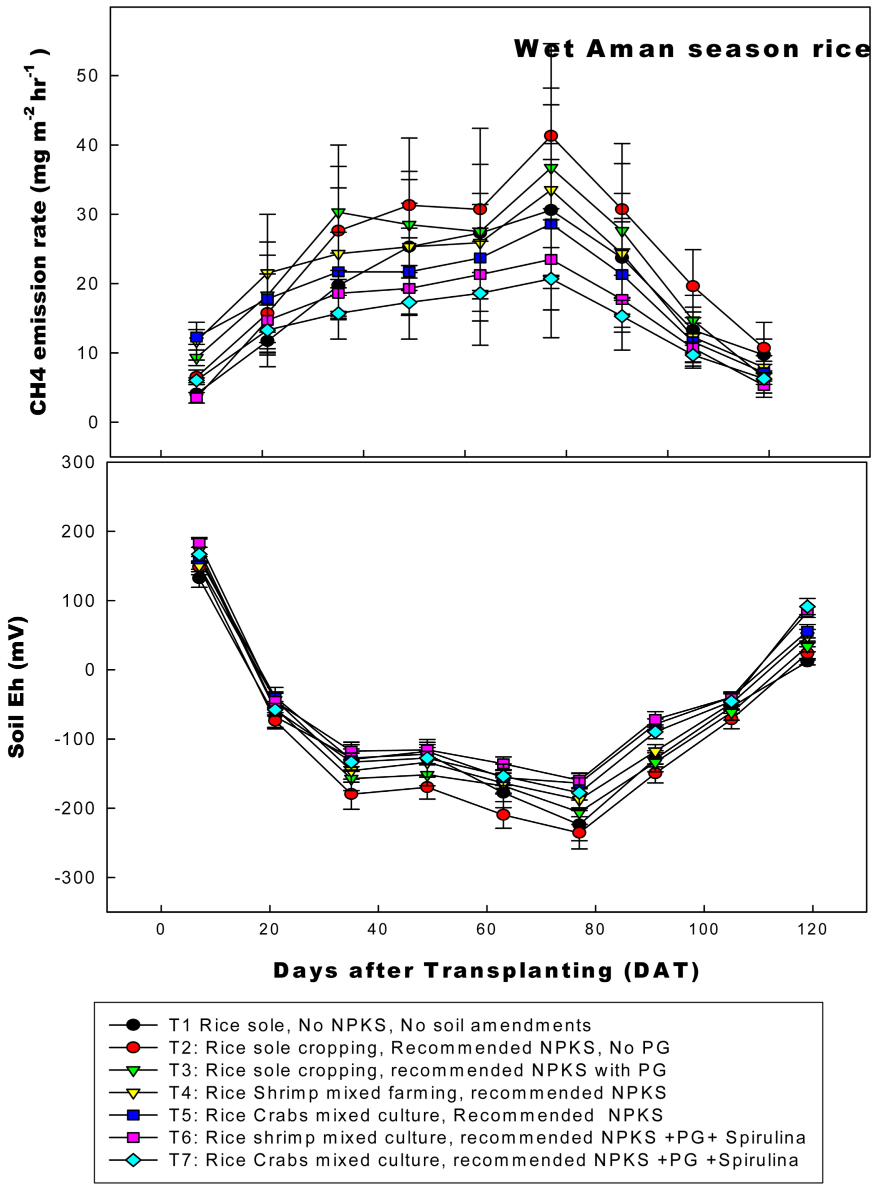
CH_4 flux measured at 21 days after rice transplanting was low, which increased gradually with plant growth and the development of soil reductive conditions during boro season rice cultivation (Figure 1(a)). Initially, CH_4 emission rates were found low, which increased gradually and reached at peak level 30 mg CH_4 m^{-2} hr^{-1} during flowering stage (70 DAT).

During wet aman season rice cultivation, comparatively higher CH_4 emissions rates were observed. The CH_4 peak 40 mg CH_4 m^{-2} hr^{-1} was recorded at around 80 days after rice transplanting (Figure 1(b)).

This discrimination in CH_4 emissions rates between the two seasons may be due to the variation in the availability of water, dissolved soil organic carbon, salts accumulation and the development of intense soil reduced conditions. The maximum CH_4 emissions rates were observed when soil redox status reached at



(a)



(b)

Figure 1. (a) CH_4 emission pattern and soil redox status under Rice-Shrimp and Rice-Crabs mixed farming during boro season; (b) CH_4 emission pattern and soil redox status under Rice-Shrimp and Rice-Crabs mixed farming during wet season aman season.

intensive reductive conditions, e.g. soil Eh value −200 mV (**Figure 1(a)**) to −240 mV (**Figure 1(b)**) in the rice rhizosphere. Afterthat, CH_4 emission rate decreased sharply alongwith improved soil redox status and plant aging. In addition, accumulation of salts concentrations from the PG amendments and Spirulina application influenced CH_4 emission rates during rice cultivation. PG released large amount of water soluble sulfate which acted as oxidizing agent and electron acceptor, eventually reduced CH_4 emissions in amended plots compared to the control plots during the rice cultivation. BGA Spirulina contributed to improve the rice rhizosphere by releasing O_2, which might have enhanced

CH_4 oxidation. The movement of shrimp and crabs around the rice field might have enhanced the oxygen penetration from the surface of water, thereby, enhanced methane oxidation.

3.2. Rice Grain Yield, Seasonal Cumulative CH_4 Flux and GWPs

Rice grain yield was low under rice sole cropping, which increased significantly with phospho-gypsum amendments and blue green algae spirulina inoculation in paddy field (Table 1).

In the dry boro season, rice grain yield 4750 kg/ha, seasonal cumulative CH_4 emissions 167 kg/ha and GWPs 4175 kg CO_2 eq. ha^{-1} were recorded from rice sole cropping with recommended NPKS (T2) fertilization. In the Rice-Shrimp mixed farming (T6) amended with phosphogypsum (PG) and blue green algae Spirulina applied paddy field plot, maximum grain yield 5200 $kg{\cdot}ha^{-1}$, total seasonal CH_4 flux 117 $kg{\cdot}ha^{-1}$ and GWPs 2925 kg CO_2 eq. ha^{-1} were recorded. On the other hand, during the wet aman season rice grain yield 3500 $kg{\cdot}ha^{-1}$, total CH_4 emission 181 $kg{\cdot}ha^{-1}$ and GWPs 4525 kg CO_2 eq. ha^{-1} were recorded from rice sole cropping amended with PG (T2), whereas Rice-Shrimp mixed farming (T6) amended with phosphogypsum (PG) and Spirulina applications significantly increased rice yield (3900 kg/ha) while decreased seasonal cumulative CH_4 emission (121 $kg{\cdot}ha^{-1}$) and GWPs (3025 kg CO_2 eq. ha^{-1}).

3.3. Rice-Shrimp Crabs Farming Productivity, Net Profit and Benefit Cost Ratio (BCR)

In the dry boro season, the net return from rice sole cropping with the recommended NPKS fertilization (T2) was found 20000 Tk./ha alongwith BCR 1.22, while Rice-Shrimp mixed farming (T4) revealed seasonal net return 35,500 Tk./ha and BCR 1.34. Further, spirulina inoculation in Rice-Shrimp mixed cultivation (T6) showed seasonal net return 38,500 Tk./ha and BCR 1.37 in Table 1. Rice-Crabs mixed farming also revealed seasonal net income (Tk. 29,000/ha) and BCR value (1.29). In the wet aman season, the net return from rice sole cropping (T2) was found 13,500 Tk./ha and BCR value was 1.16., which were increased to 24,000 Tk./ha and BCR value 1.26 with spirulina inoculated Rice-Shrimp mixed field plots (T6). Rice-Crabs mixed farming (T7) showed seasonal net income (Tk.18,500/ha) and BCR value (1.19), which indicates less outputs compared to Rice-Shrimp cropping practice.

The post harvest soil properties such as soil redox status, organic matter content in soil, available P, available S, exchangeable Ca, and K cations concentrations were increased with PG and Spirulina application in Rice-Shrimp and Rice-Crabs mixed cultivations. The soil organic matter and total N content increased significantly in the phospho-gypsum amended and BGA Spirulina applied field soil. The higher organic matter 2.6% - 3.10% were found in the PG amended and Spirulina inoculated Rice-Shrimp and Rice-Crabs mixed farming compared to non-amended rice sole cropping organic matter contents (2.1%). The available P

Table 1. Rice productivity, cumulative CH_4 flux and global warming potentials, net return and BCR under Rice-Shrimp and Rice-Crabs mixed farming practices.

Rice growing seasons (A)	Treatments (B) Rice-Shrimp crabs mixed farming with soil amendments	Grain yield (kg·ha^{-1})	Gross return (Tk./ha)	Total variable cost (Tk./ha)	Cumulative CH_4 flux (kg ha^{-1} season^{-1})	GWP (kg CO_2 eq. ha^{-1})	Net return Tk. ha^{-1}	Benefit to cost ratio (BCR)
Wet season (rainfed aman)	T_1: Rice sole cropping without NPKS, and no soil amendments	1500 g	48,000 g	57,000 f	133.5 d	3337 d	-	0.84 d
	T_2: Rice sole cropping (NPKS, farmers' practice) without soil amendments	3500 ef	96,000 f	82,500 d	181.0 a	4525 a	13,500 f	1.16 cd
	T_3: Rice sole cropping (FP) with PG	3600 e	99500 ef	85,000 c	166.0 b	4150 ab	14,500 f	1.17 cd
	T_4: Rice-Shrimp mixed culture with PG	3700 de	112,000 de	90,500 b	151.6 bc	3790 bc	21,500 d	1.23 bc
	T_5: Rice-Crabs mixed farming with PG	3300 f	106,500 e	88,500 bc	133.0 d	3325 d	18,000 de	1.20 c
	T_6: Rice-Shrimp mixed farming + PG with Spirulina	3900 d	115,500 d	91,500 b	121.0 e	3025 e	24,000 cd	1.26 bc
	T_7: Rice-Crabs mixed farming + PG with Spirulina	3500 ef	110,000 de	92,500 b	115.7 e	2767 f	18,500 e	1.19 cd
Dry season (boro)	T_1: Rice sole cropping without NPKS, and no soil amendments	1000 h	30,500 h	65,500 e	121.0 e	3025 e	-	0.51 e
	T_2: Rice sole cropping (NPKS 100%) without soil amendments	3750	115,000 d	90,000 b	167.0 b	4175 ab	20,000 cd	1.22 bc
	T_3: Rice sole cropping (FP) with PG	3900 ab	128,500 cd	98,500 ab	155.0 bc	3875 b	30,000 bc	1.30 b
	T_4: Rice-Shrimp mixed culture with PG	4100 ab	140,700 b	105,200 a	141.0 c	3525 c	35,500 b	1.34 ab
	T_5: Rice-Crabs mixed farming with PG	3800 c	127,000 cd	99,500 ab	129.0 d	3225 d	27,500 c	1.28 bc
	T_6: Rice-Shrimp mixed farming + PG with Spirulina	4500 a	143,500 a	105,000 a	117.0 e	2925 e	38,500 a	1.37 a
	T_7: Rice-Crabs mixed farming + PG with Spirulina	4000 cd	130,500 c	101,500 ab	105.6 f	2640 f	29,000 bc	1.29 bc
ANOVA	A	*	**	**	*	*	**	*
	B	*	**	**	**	**	**	**
	A × B	*	**	**	*	*	**	*

Note: In each column, treatments means followed by same letters do not differ significantly, but different letters differ significantly. * and ** indicate significant at 5% and 1%, respectively.

and available S, water soluble iron and sulfate concentrations were increased significantly with PG amendments and Spirulina application (**Table 2**). Soil electrical conductivity (EC) value showed significant variation due to PG amendments and Spirulina application (**Table 2**). The higher EC value 7.6 dS/m and 7.5 dS//m were recorded in the non-amended field plots, while PG amended and Spirulina applied field soil revealed lower EC value 6.2 - 6.5 dS/m. The concentration of Na was decreased with PG amendments and Spirulina application. The ratio of Na^+/K^+ and Na^+/Ca^{2+} values decreased with PG and Spirulina application in Rice-Shrimp and Rice-Crabs mixed cultured field plots. Soil pH and EC values gradually decreased with PG amendments and Spirulina application in field plots. The exchangeable cations such as calcium (Ca^{2+}), potassium (K^+) and sodium (Na^+) showed significant variation due to PG amendments. The exchangeable Ca^{2+} contents were found 3.3 - 4.3 meq/100g soil in the PG amended soil, while the lowest value 1.9 meq/100g was recorded in control treatment (T1). The higher exchangeable potassium (K^+) content 0.58 to 0.69 meq/100g were recorded in the PG amended and Spirulina applied soil compared to control treatment (T1) 0.41 meq/100g soil. The exchangeable sodium (Na^+) was found 4.8 meq/100g soil in the control treatment (T1), which decreased with PG amendments. The maximum value of Na^+/Ca^{2+} was found 2.5 (control T1), while the lowest value was found 1.13 - 1.15 in Rice-Shrimp amended with PG Spirulina (T6) and Rice-Crabs amended with PG Spirulina (T7).

4. Discussion

It has already been reported that wetland rice paddy acts as a major source of CH_4, therefore integrated Rice-Shrimp and Rice-Crabs farming has been adopted to cope in the coastal ecosystem. A significant changes in CH_4 emissions, nutrients cycling, soil properties and the overall ecosystem functions are expected following paddy fields conversion to Rice-Shrimp/fish and Rice-Crabs farming systems. In this experimental study, CH_4 flux measured at 14 days after rice transplanting was low, which increased gradually with plant growth and reached at peak level during flowering to reproductive stages of rice growth (70 - 84 DAT) (**Figure 1(a)** and **Figure 1(b)**). This may be due to the development of intense soil reduced conditions, e.g. Eh −200 mV to −240 mV and the availability of labile organic carbon in the rice rhizosphere [21]. However, CH_4 emission rate decreased sharply at rice ripening stage. This decline in CH_4 emission could be related to plant aging and accumulation of salts concentrations in rice rhizospheric zone. In this study, phosphogypsum (PG) amendment and Spirulina inoculation decreased CH_4 emission rates, due to release of large amount water soluble sulfate and dissolved iron (DFe, Fe^{3+}) which acted as oxidizing agent and electron acceptor, thereby reduced CH_4 emissions [22]. It was also reported that CH_4 emissions were decreased by 23%, 27% and 61% with gypsum applications 1 Mg/ha, 2.5 Mg/ha and 5.0 Mg/ha, respectively at 25 mM NaCl salinity level [23]. Furthermore, under the salinity level 25 mM to 50 mM, CH_4 emissions were

Table 2. Post harvest soil properties under Rice-Shrimp and Rice-Crabs mixed farming (after two seasons of cropping).

Treatments	Soil pH (1:5 with H_2O)	EC (dS/m)	OM (%)	T-N (%)	Av-P (ppm)	Av. S (ppm)	Exchangeable cations (meq./100g)			Water soluble Fe (mg/kg)	Water soluble SO_4^{2-} (mg/kg)	Na^+/K^+	Na^+/Ca^{2+}
							Ca	K	Na				
T_1: Rice sole cropping without NPKS, and no soil amendments	7.8	7.6	1.9	0.11	29.8	18.6	1.9	0.41	4.8	1.1	21.5	11.7	2.51
T_2: Rice sole cropping, FP without soil amendments	7.75	7.5	2.1	0.43	31.6	20.5	2.5	0.49	4.7	1.5	25.6	9.6	1.90
T_3: Rice sole cropping, FP with PG	7.65	6.5	2.6	0.49	33.5	23.6	3.3	0.58	4.3	2.1	33.3	7.4	1.30
T_4: Rice-Shrimp mixed culture with PG	7.67	6.2	2.8	0.55	35.6	25.5	3.5	0.60	4.4	2.6	38.5	7.3	1.25
T_5: Rice-Crabs mixed farming with PG	7.50	6.4	2.7	0.65	36.3	27.3	3.6	0.61	4.7	2.9	41.7	7.4	1.27
T_6: Rice-Shrimp mixed farming + PG with Spirulina	7.60	6.0	3.15	0.69	37.6	28.5	4.0	0.69	4.6	3.1	53.6	7.1	1.15
T_7: Rice-Crabs mixed farming + PG with Spirulina	7.68	6.2	3.10	0.68	38.3	29.7	4.3	0.67	4.9	3.3	57.3	7.6	1.13
$LSD_{0.05}$	0.15	0.25	0.41	0.13	2.8	2.6	0.9	0.15	0.20	0.17	5.6	1.3	0.15
Level of significance	ns	*	*	*	*	**		**	*	**	***	**	**

Note: ns means not significant, * and ** indicate significant at 5% and 1%, respectively.

suppressed with phospho-gypsum and biochar amendments (5 t/ha) [24]. Interesting to mention that CH_4 emissions were decreased by 20% - 48% in rice-fish integrated systems compared to rice sole cropping [25]. It was also reported that seasonal CH_4 emissions from crab-fish framing wetlands were decreased by 52% compared to rice paddies [26]. The CH_4 fluxes were negatively related to water dissolved oxygen (DO) concentration but positively related to soil/sediment dissolved organic carbon (DOC) content in crab-fish farming wetlands.

The movement of shrimp and crabs in the rice planted field plots improved soil redox status by increasing dissolved oxygen concentration in the rice rhizospheric zone. Furthermore, soil amendment with Phosphogypsum and Spirulina inoculation released large amount of Ca^{2+}, K^+, and S which might have replaced Na^+ ions from the clay particles or exchangeable sites. Although soil redox value decreased towards −150 mV to −220 mV in non-amended rice planted field plots during rice reproductive growth stage, PG and BGA Spirulina applied field soil showed improved soil redox status to some extent. However, Soil Eh value dropped down at rice grain maturation stage around two weeks before rice harvest.

In this study, rice grain yield was low (3500 kg/ha) under rice sole cropping, which increased about 9% - 16% with phosphogypsum amendments and blue green algae spirulina inoculation in paddy field (Table 1). In the dry boro season the seasonal cumulative CH_4 emission 167 kg/ha and GWPs 4175 kg CO_2 eq. ha^{-1} were recorded from rice sole cropping with recommended NPKS (T2), which decreased significantly ($P < 0.01$) under Rice-Shrimp and Rice-Crabs mixed farming amended with phosphogypsum (PG) and blue green algae Spirulina. On the otherhand, during the wet aman season cumulative CH_4 emission 181 kg/ha and GWPs 4525 kg CO_2 eq. ha^{-1} were recorded from rice sole cropping (T2), which were decreased by 33.0% under Rice-Shrimp mixed farming and 36% - 38% under Rice-Crabs mixed farming, respectively. From this study, the maximum net seasonal return Tk. 41,500/ha and highest benefit to cost ratio (BCR) 1.39 were found in Rice-Shrimp mixed farming amended with PG Spirulina (T6) followed by Tk. 29,000/ha and benefit to cost ratio (BCR) index 1.29 in Rice-Crabs mixed farming during dry boro season. In the wet aman season, maximum net seasonal return Tk. 24,000/ha and highest benefit to cost ratio (BCR) index 1.26 were found in Rice-Shrimp mixed farming amended with PG Spirulina (T6) followed by Tk. 18,000/ha and benefit to cost ratio (BCR) 1.19 in Rice-Crabs mixed farming. The lower net seasonal return and BCR ratio were found in the wet aman season compared to dry boro season, which may be due to lower yield potentials of aman rice cultivar. Higher productivity as well as net annual return under Rice-Crabs [27] and rice-fish co-farming were obtained compared to rice monoculture [28] [29].

After harvesting rice, the overall soil properties such as soil redox status, organic matter content, electrical conductivity, available P, available S, exchangeable K^+ and Ca^{2+}, K^+/Na^+, Ca^{2+}/Na^+ ratios, etc. were increased with phospho-gypsum amendment and BGA spirulina inoculation in rice planted field plots. The highest ratios of K^+/Na^+ and Ca^+/Na^+ were found in the extract of saline soil (at 25 mM) with phospho-gypsum amendments and Spirulina inoculation. Furthermore, soil SO_4^{2-}, NO_3^-, Mn^{4+} and Fe^{3+} contents in rice root rhizosphere were increased in the amended saline soils, which caused significant reduction in seasonal methane emissions. Soil amendments with PG and BGA Spirulina inoculation decreased soil pH and EC value, probably due to the acidifying effect of organic acids produced from the decomposition of organic materials and Phosphogypsum, eventually improved tolerance to salinity and enhanced rice yield and overall Rice-Shrimp crabs' productivity.

5. Conclusion

Rice-Shrimp and Rice-Crabs mixed farming revealed better performance in regards to sustainable rice yield, overall productivity and profitability than conventional mono rice cropping. From environmental and climate change points of view, it was found that Rice-Shrimp mixed farming (T6) and Rice-Crabs mixed farming (T7) practices significantly lowered GWPs compared to the rice sole cropping system. In the dry boro season, the maximum GWPs 4175 kg CO_2 eq. ha^{-1} was recorded from rice sole cropping (T2), which was decreased by 30% and 36.7% under Rice-Shrimp (T6) and Rice-Crabs (T7) mixed farming practices, respectively. Furthermore, in the wet aman season, maximum GWP 4525 kg CO_2 eq. ha^{-1} was recorded from rice sole cropping (T2), which was decreased by 33.0% under Rice-Shrimp mixed farming and 38.8% under Rice-Crabs mixed farming, respectively. Rice grain yield was low under rice sole cropping (3500 kg/ha in wet aman season, 3750 kg/ha in dry boro season), which was increased by 11.0% and 14.7% under Rice-Shrimp mixed farming amended with PG and Spirulina (T6) during wet aman and dry boro season, respectively. The overall productivity, net annual return and soil properties were also increased under Rice-Shrimp and Rice-Crabs mixed farming practices amended with PG along with BGA spirulina inoculated saline paddy field. Conclusively, Rice-Shrimp and Rice-Crabs mixed farming practices are recommended for sustainability and adaptations in the coastal wetlands as well as mitigations of GWPs instead of conventional mono rice cropping.

Authors' Contributions

Conceptualization: Ali, M.A.; methodology: Ali, M.A. and Haque, S.M.; formal analysis: Rabbi, S.K, Sohrawardi, K. and Sarker, S.K.; writing original draft preparation: Ali, M.A., Haque, S.M. and Mahjabeen, R.; writing review and editing: Ali, M.A and Hiya, H.J.

Ethical Approval

All authors have read and agreed to publish the manuscript.

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Conflicts of Interest

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

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