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# Integration of Vegetables and Fish with Rice in Rain-Fed Farmland: Towards Sustainable Agriculture

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**Abstract:** Sustainability in aquaculture or agriculture production is depended on its successive use of natural resources that can ensure economic increment and sustainability of the livelihood of people. The objective of the study was to find out suitable combination of rice-fish-vegetable to be cultured in rainfed rice field. Two experiments were conducted for 4 months under rainfed condition. Two rice varieties (BRRI-51 and BRRI-52), three different fish species. i.e., *Cyprinus carpio var. communis*, *Barbonymus gonionotus* and *Oreochromis niloticus* and two combinations of vegetables (Red amaranth + Indian spinach and Cucumber + Water spinach) were selected for these experiments. Significantly higher growth and production performance of fish, *B. gonionotus* were recorded in both of the experiments. Furthermore, between the rice varieties, BRRI-52 showed significantly higher grain yield, biological yield and harvest index. However, vegetable combination did not show any significant difference between the experiment. Finally, considering economic performance, integration of BRRI-52, *B. gonionotus* and Cucumber-spinach combinations was provided significantly higher net benefit and benefit-cost ratio (BCR). Therefore, combination of rice-fish-vegetable BRRI-52, *B. gonionotus* and Cucumber-spinach is recommended to improve food security and sustainability for resource-limited farmers in rainfed rice field. Rice-fish-vegetable integrated culture could address the sustainable development goals (SDG) and therefore policy implications should be considered for institutional support, technical facilities and extension services to increase the knowledge of farmers and to uplift the productivity and profitability.

**Keywords:** integrated culture; fish growth performance; *Barbonymus gonionotus*; economics; food security; sustainability

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**Citation:** Jewel, M.A.S.; Haque, M.A.; Ali, S.M.W.; Pervin, M.E.; Ahmed, M.G.U.; Islam, M.S.; Hossain, M.B.; Albeshr, M.F.; Arai, T. Integration of Vegetables and Fish with Rice in Rain-Fed Farmland: Towards Sustainable Agriculture. *Agriculture* **2023**, *13*, 755. https://doi.org/10.3390/agriculture13040755

Academic Editor: Ronald Kennedy Luz

Received: 9 February 2023
Revised: 18 March 2023
Accepted: 21 March 2023
Published: 24 March 2023



## 1. Introduction

Rice and fish are among the most produced and consumed foods in Bangladesh, and both constitute part of the country's daily eating culture, especially for the country's poorest residents [1]. Rice is the main agricultural crop in Bangladesh with an annual production of 36.6 million tons in the fiscal year 2019–2020 (July–June) from the official estimates of the Department of Agriculture Extension (DAE), while annual fish production is

4.621 million MT [2]. The demand for rice and fish is constantly rising in Bangladesh due to rapid population growth (1.37% per annum), diminishing of arable lands and ongoing climate change impact [3,4]. Sometimes overuse of fertilizer and pesticides in rice fields are contaminating the natural environment. A sustainable option that can produce rice and fish in a sustainable way is therefore urgently needed. Nevertheless, integrated rice-fish-vegetable farming can offer a solution to this issue by contributing to food production and income security generation by using less land areas [1].

Bangladesh is vulnerable to climate change due to its high rainfall variability, rising temperatures, and rain deficits [5]. Season, topography, and location all are affecting the type and size of the country's environment. Inundation during monsoon season reduces the productivity and destroy the crops by forming rain-fed areas of more than 2.83 million ha among 10.14 million ha of total rice fields areas of Bangladesh [6]. Even after the monsoons have passed, the rice fields in this area continue to be rainfed, making them a rare, transitory, and ever-evolving productive ecosystem. Thus, an understanding of the ecology of these waterlogged rainfed rice fields, therefore, creates essential potentiality for raising rice-fish-vegetable cropping effectively. Furthermore, upgrading the rainfed agriculture also has a large social, economic and environmental benefits particularly in reducing poverty and boosting the economy of the country. For instance, nearly 40% of India's estimated population was found to be supported by rain-fed areas in 2011 [7]. Up to 80% of Cambodia's rice farmland is still used for rice field fisheries [8]. Furthermore, community fish refuges and "fish friendly" irrigation are two examples of recent rice field fisheries research and innovations for enhancing ecosystem connectivity, biodiversity preservation, and food and water security in the floodplains of Combodia and lower Makong basin [9,10].

Fish introduced into rice fields in a manageable way have several positive effects, such as increasing rice output by eating harmful insects, pests, and weeds, and improving agricultural fertility by producing nitrogen and phosphorus Bashir et al. [11]) which also supports a wider range of organisms and the reuse of nutrients [8]). Consequently, land resources are being used more effectively and economically [12]. Fish culture also enhances plant height, effective tillering rate, and grains per tiller while decreasing the production rate of empty grains [13]. Furthermore, rice fields offer fish with planktonic, periphytic and benthic foods [14] Shading by rice plants and vegetable cropping also maintains the favorable water temperature for fish during the hot summer months [15]. Moreover, dyke cropping with vegetables provided with the opportunity for nutritional and economic betterment of the farmers. Therefore, sustainability in terms of productivity of rice, fish and profitability of the farms are achieved. Dyke cropping with vegetable is mainly practiced in modified rice field, known as "Gher", in Bangladesh whereas prawn is cultivated with rice and vegetable [6]. According to Marques et al. [16], integrated rice-fish-vegetable systems help many nations' aquaculture systems become more socially, economically, and environmentally sustainable. Integration of rice-fish-vegetable has also been widely used in India that was reported by Sathoria and Roy [17].

Although rice-fish-vegetable farming system has great promise in rain-fed agriculture, it is still in its early stages of development in Bangladesh [6,18]). Sustainable rice-fish farming not only offers healthy food, but also stabilizes the economic situation of disadvantaged farmers and reduces environmental repercussions. Competition for scarce resources like arable land and clean water is already limiting humanity's capacity to feed a rapidly growing population. Using improve varieties, choosing better management system, reducing post-harvest loss and intensification of cropping system are some of the prerequisite for sustainable rice-fish-vegetable culture in Bangladesh and other similar areas of the world.

Apparently, rice varieties suitable for rainfed agriculture should have specific adaptive traits such as short culture duration, medium to tall height with long leaves and less susceptible to pests and diseases [19,20]. Varieties of BRRI are characterized with shorter culture duration, high yield, desired grain quality, higher suitability and market demand. These varieties can also withstand climatic shocks such as submergence which causes a great yield loss to the farmers [21]. Fish species, capable of thriving in shallow water, tolerate to temperature fluctuations, high turbidity and grow into the marketable size in within a shorter period of time are selected for integrated culture. Farmers are usually found to paying emphasis on indigenous species such as rohu (*Labeo rohita*), catla (*Catla catla*), mrigal (*Cirrhinus cirrhosus*) kalibaos (*Labeo calbasu*) and exotic species like silver barb (*Barbonymus gonionotus*), tilapia (*Oreochromis niloticus*), and common carp (*Cyprinus carpio*) [22]. However, there are some contradictory predictions on the selection of suitable fish species for rice-fish integrated farming system which may be due to the variation in growth performance, market demand and consumer acceptability. In rice-fish-vegetable farming system, dyke area of rice field crates an avenue for vegetable cultivation. Vegetable cropping on dyke is considered as an indigenous knowledge-based practice which is economically sound, environment friendly and socially acceptable. Study conducted by Akter et al. [23] reported 53,962.09 kg/ha vegetables production from dyke cropping, which is entirely a surplus production. However, vegetable cropping on dyke also needs some special attention as farmer's financial condition, soil type of dyke, culture duration, types of species, seed cost, productivity and market demand are all influencing the outcome of dyke cropping [23]. Therefore, in rice-fish-vegetable culture system, interaction between rice, fish and vegetables and their outcomes needs to be thoroughly assessed. This type of integration is depending on the seasonality and profitability of each component. As for example, species of fish, their stocking density, stocking size, rice variety, types of vegetable, their growing season and market price are entirely interacted to provide a good profit margin from integrated culture system. However, scientific knowledge regarding the above-mentioned issues of small-scale farmers is limited. Although most of the researchers used an integrated culture of rice with fish [14,17,24–27], the inclusion of vegetables with rice and fish and its economic evolution is limited.

Global food security is an acute problem as people already suffer from hunger, and thus achieving zero hunger by 2030 might be an ambitious goal. The world population is expanding rapidly, estimated to reach 9.7 billion in 2050 from 7.7 billion in 2019 [28]. To feed this rising global population, food production must increase and therefore sustainable integrated farming of rice-fish-vegetable can be considered as one of the main food production systems and the most likely to be used to improve global human nutrition and food security. Therefore, the hypothesis of this study is that different fish species, rice variety and vegetable combination may have significant effect on productivity and economic performance. In this context, the objectives of the present study were to select suitable fish species, rice varieties and vegetables for an integrated culture of rice-fish-vegetables in rainfed conditions.

## 2. Materials and Methods

### *2.1. Study Area and Experimental Design*

The study site is located in Motihar sub-district (between 24° 21′ 48.59′′ N and 88° 37′ 40.96′′ E) of Rajshahi City, Bangladesh. The climate of Rajshahi is typically characterized by monsoons (precipitations 1221.0 mm/year), high temperatures (Avg. 30 °C), and high humidity. The annual temperature is 28.49 °C, which is 0.75% greater than Bangladesh's averages. It is situated 20 m above sea level. Two experiments were conducted for a period of four months from August to November 2015 in six experimental rice fields (Figure 1) of the Department of Agronomy and Agricultural Extension, University of Rajshahi. Rice fields were rectangular in shape and all were rainfed. The average area of the rice fields was 0.024 ha (5.92 decimal) (Figure 2). Each experiment had three different treatments with two replicates. Component selections were done on the basis of national priority and market availability throughout the counter as well. The present study had used 2 rice varieties (BRRI 51, BRRI 52), 3 fish species (*Cyprinus carpio var. communis, Barbonymus gonionotus and Oreochromis niloticus*) and 2 combinations of vegetables i.e., (a) Red amaranth (*Amaranthus cruentus*) and Indian spinach (*Spinacia oleracea*), (b) Cucumber (*Cucumis sativus*) and Water spinach (*Ipomoea aquatica*) to find out suitable rice, fish and vegetables combination to recommend for the integrated farming system. The experimental combinations were running by permutation complexes of sample numbers in different layouts. The treatments of each experiment were assigned as follows:

Experiment-1

$T_1$ = BRRI-52 + 4940 individuals/ha of *Cyprinus carpio* + Red amaranth (*Amaranthus gangeticus*) + Indian spinach-green (*Basella alba*).

$T_2$ = BRRI-52 + 4940 individuals/ha of *Barbonymus gonionotus* + Red amaranth (*Amaranthus gangeticus*) + Indian spinach-green (*Basella alba*).

$T_3$ (BRRI-52 + 4940 individuals/ha of *Oreochromis niloticus* + Red amaranth (*Amaranthus gangeticus*) + Indian spinach-green (*Basella alba*).

Experiment-2

$T_1$ = BRRI-51 + 4940 individuals/ha of *Cyprinus carpio* + Cucumber (*Cucumis sativus*) + Water spinach (*Ipomoea aquatica*).

$T_2$ = BRRI-51 + 4940 individuals/ha of *Barbonymus gonionotus* + Cucumber (*Cucumis sativus*) + Water spinach (*Ipomoea aquatica*).

$T_3$ = BRRI-51 + 4940 individuals/ha of *Oreochromis niloticus* + Cucumber (*Cucumis sativus*) + Water spinach (*Ipomoea aquatica*).

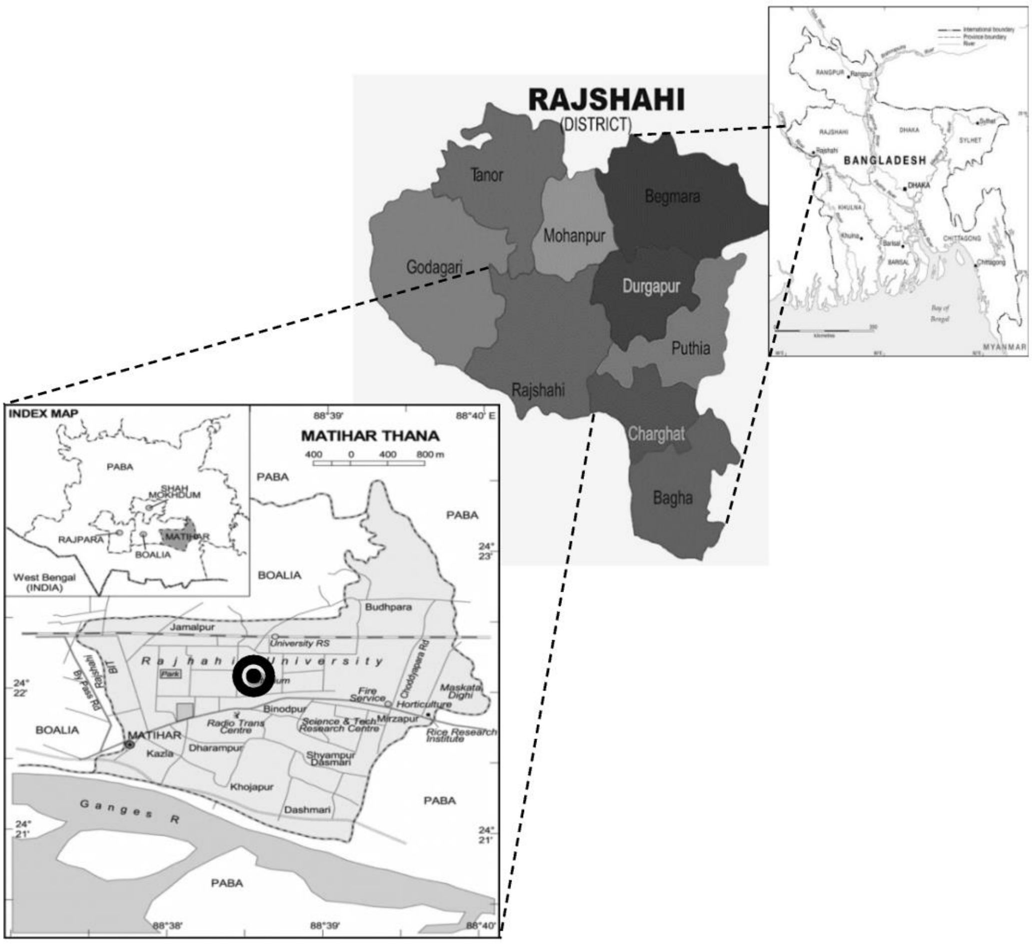


**Figure 1.** Location of the study area indicating the rice fields (black circle) at the Department of Agronomy and Agricultural Extension, University of Rajshahi, Bangladesh.

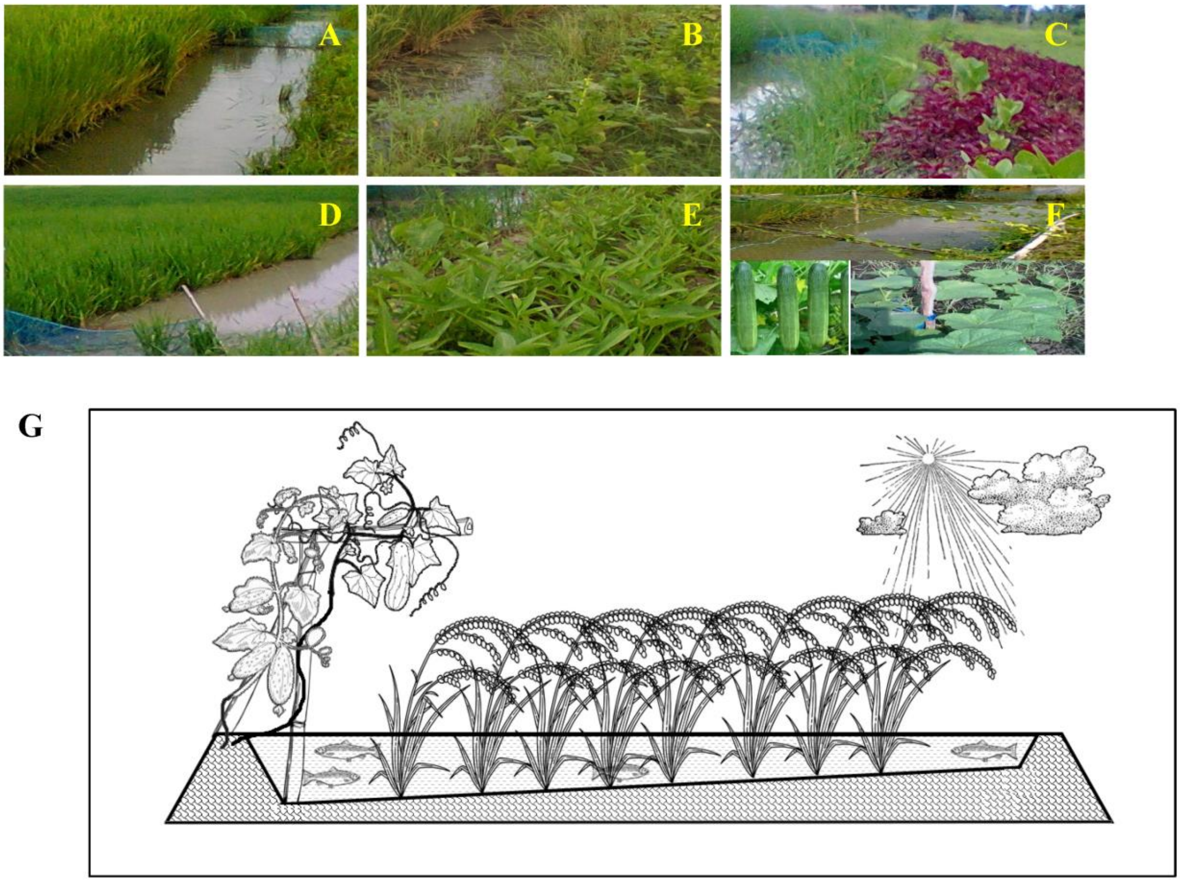


**Figure 2.** Combination for experiment-1 (**A** = BRRI 52, **B** = Indian spinach, **C** = red amaranth) and experiment-2 (**D** = BRRI 51, **E** = water spinach, **F** = cucumber, **G** = Methodological sketch of an integrated farming system).

### 2.2. Management of Rice Fields

The rice fields were ploughed with a power tiller and then appropriately leveled by laddering to maintain uniform water depth. Dyke around the land was constructed at a height of 25 cm. Before the rice seedlings were transplanted, the weeds in the fields were cleared by hand picking. In order to provide fish with a place of refuge during periods of high temperatures and low water depth, a small ditch (1.5 m $\times$ 1.5 m $\times$ 1 m) was created in the field's lower part. The rice fields were fertilized with urea (200 kg/ha), TSP (100 kg/ha), muriate of potash (MoP) (50 kg/ha), and gypsum (20 kg/ha). A total of 1500 kg/ha of organic fertilizer (cow dung) was also applied. To provide the best possible results, the rice seedlings were grown in a designated seedbed near the chosen fields. To prepare for their eventual replanting in the experimental rice field, the seedlings were carefully dug out. Rice seedlings were planted at a row spacing of 35 cm alternated with 15 cm [29]. Twenty cm spacing between each plant was strictly adhered to. Fish were supplied at a density of 4940 fish per hectare (15 days after the rice seedlings were transplanted) across all treatment groups. The mean initial weight of *C. carpio, B. gonionotus* and *O. niloticus* was 19.56 $\pm$ 1.56, 19.78 $\pm$ 1.30 and 18.17 $\pm$ 0.38 g for experiment-1 and 20.58 $\pm$ 2.15, 19.58 $\pm$ 0.52 and 18.92 $\pm$ 0.57 g for experiment-2 at $T_1$, $T_2$ and $T_3$, respectively. Vegetable seeds were planted along with the rice field border with small fences for the protection from predators. No extra fertilizer was provided to the vegetable plants. Periodic water was supplied from rain feed rice field if any severe dry conditions were observed. Fishes were harvested followed by rice harvesting after 4 months of days after transplantation (DAT). Rice harvesting was performed manually with the use of harvesting tools using sickles (*kanchi* in Bengali), consisting of a wooden handle and a knife blade. The fish were collected by many rounds of netting, followed by the draining of the ditches.

### *2.3. Monitoring of Physic-Chemical Parameters of Water*

Each month, between 10:00 and 11:00 a.m., dark bottles were used to collect water samples for study of physicochemical characteristics. A Celsius thermometer was used to determine the water's temperature. Measurements of transparency were made using a black and white, 30 cm diameter, standard color-coded Secchi disc. An electronic pH meter was used to analyze the water's pH value (Jenway 3020). A DO meter was used to measure the concentration of dissolved oxygen (Lutron DO-5509). The HACH kit was used to determine the alkalinity and ammonia-nitrogen levels (model FF-2, No. 2430-01; Loveland, CO, USA). An Hach Kit (DR/2010, a direct reading spectrophotometer) calibrated with high-range chemicals was used to assess phosphate-phosphorus ($PO_4$-P) and nitrate-nitrogen ($NO_3$-N) concentrations (Phos Ver. 3 Phosphate Rea-gent Powder Pillows for 25 mL sample for phosphate-phosphorus analysis and Nitra Ver. 5 Nitrate Reagent Powder Pillows for 25 mL sample for Nitrate-nitrogen).

### *2.4. Monitoring of Plankton*

After collecting 50 L of water from around 10–12 cm below the surface, the water was filtered through a plankton net with a mesh size of 25 m, then condensed to 25 mL and promptly preserved in 4% formalin. After shaking up the material, one milliliter was poured into a Sedgewick Rafter counting cell and examined with binoculars microscope (Olympus, M-4000D). [30]. Plankton were identified to the genus level using the keys from Dudgeon [31], Prescott [32] and Bellinger [33]. The number of plankton in the S-R cell was determined after the formula of Stirling [34]:

$$N = \frac{A \times 1000 \times C}{V \times F \times L} \tag{1}$$

where, N = No. of plankton cells per liter, A = Total no. of plankton counted, C = Volume of final concentrate of samples in ml, V = Volume of a field in cubic millimeter, F = Number of the fields counted, L= Volume of original water in liter.

### *2.5. Fish Growth Parameters*

Growth, survival and production performances of fishes were analyzed as follows [27]:

$$\text{Weight gain (g) = Mean final weight (g)} - \text{Mean initial weight (g)} \tag{2}$$

$$\mathrm{Specificgrowthrate, SGR}(\%, \mathrm{bw/d}) = \frac{\mathrm{L_n finalweight} - L_n initalweight}{Cultureperiod} \times 100 \tag{3}$$

$$\mathrm{Survivalrate}(\%) = \frac{No.offishharvested}{No.offishstocked} \times 100 \tag{4}$$

$$\text{Fish yield (kg/ha) = Fish biomass at harvest - Fish biomass at stock} \tag{5}$$

### *2.6. Growth and Production of Rice Varieties*

During transplanting, 5 hills were selected randomly and marked with bamboo sticks to record the data on plant height and number of tillers hill$^{-1}$. Measurement of plant height and number of tillers were recorded at 15 days interval initiating from the beginning of 30 DAT to the harvesting. The following parameters were measured to evaluate the performance of rice varieties. Plant height (selected five plants) was measured (cm) from the ground level to the tip of the longest panicle. Tillers that had at least one leaf visible were counted. It included both productive and nonbearing tillers. Each panicle was inspected for the existence of filled grains, which were defined as spikelets that contained some kind of edible substance. Plants were threshed for their grains, which were then washed, dried, and weighed. Grain yield (t/ha) was calculated from the dry weight of grains across all fields. Final grain weight was adjusted to 14% moisture content by using the following formula:

$$\text{Moisture}(\%) = \frac{\text{Freshweight} - \text{Ovendryweight}}{\text{Freshweight}} \times 100 \tag{6}$$

Straws obtained from each plot were sun-dried and weighed to record the straw yield-plot and converted (t/ha). Grain yield and straw yield were altogether regarded as biological yield (t/ha). The biological yield was calculated with the following formula:

$$\text{Biological yield (t/ha)} = \text{Grain yield (t/ha)} + \text{Straw yield (t/ha)}. \tag{7}$$

Harvest index (%) denotes the ratio of economic yield to biological yield and was calculated with the following formula [35]:

$$\text{Harvestindex}(\%) = \frac{\text{Economicyield}}{\text{Biologicalyield}} \times 100 \tag{8}$$

where economic yield represents grain yield and biological yield represents grain yield plus straw yield.

### 2.7. Economic Analysis

An economic analysis was conducted at the end of the study period to calculate the net return and benefit-cost ratio of the two studies by following the equations of Asaduzzaman et al. [36]:

$$R = I - (FC + VC + Ii) \tag{9}$$

where, R = Net return, I = Income from fish sale, FC = fixed/common costs, VC = variable costs and Ii = interest on inputs.

The benefit-cost ratio was determined as:

Benefit cost ratio (BCR) = Total net return/Total input cost.

### 2.8. Statistical Analysis

One-way ANOVA was used to examine data at a 95% level of confidence on water quality, plankton abundance, fish development and yield characteristics, and economic performance. When the ANOVA revealed a statistically significant mean effect, the Duncan New Multiple Range Test was performed [37] at 5% level of significance [38]. The t-test was used to analyze the differences in rice's growth and yield between the two experiments. For this study, we used arcsine transformation to examine the percentage and ratio data. ation. The statistical packages used for the analysis of data include Microsoft excel (version, 2010) and SPSS (Statistical Package for Social Science) version 20.0 (IBM Corporation, Armonk, NY, USA). Pearson correlation plots were done by Past 3 among fishes' growth factors with different environmental variables accordingly.

## 3. Results and Discussion

### 3.1. Water Quality Parameters

In experiment-1 and experiment-2, the highest value of transparency (17.92 ± 0.29 cm), DO (5.30 ± 0.04 mg/L), $NH_3$-N (0.14 ± 0.00 mg/L), $PO_4$-P (0.39 ± 0.00 mg/L) and $NO_3$-N (1.82 ± 0.01 mg/L) was observed in treatment $T_2$. There were significant differences ($p < 0.05$) in the mean values of transparency, DO, $NH_3$-N, $PO_4$-P and $NO_3$-N in both experiment-1 and experiment-2. The mean values of temperature, pH and alkalinity in both experieriment-1 and experiment-2 were insignificant ($p > 0.05$) during the study period (Table 1). In the present study, the mean temperatures were higher than the recommended range (25.5 to 29.8 °C) might be due to the reduced water depth during the last few months of the culture periods [39]. In both experiment-1 and experiment-2, transparency was lower at $T_2$, which was attributed to the higher abundance of phytoplankton and zooplankton at $T_2$ of both experimental plots. Lower transparency in $T_1$ of both experiments was attributed to the turbidity of water due to the bottom-feeding nature of *C. carpio*, which agreed with the findings of Frei et al. [40] and Hossain et al. [41]. Increased burring activity by *C. carpio* also limits the light penetration and reduced the photosynthetic activity phytoplankton, which reduced DO in $T_1$ for both of the experiments. Reduced DO in rice field was also reported by Saikia and Das [42]. pH was higher at $T_1$ of both experiments and this phenomenon can be explained by the enhanced oxidation of organic matter by the consumption of dissolved oxygen by fish and the subsequent release of higher amount of $CO_2$ in the water [43]. Higher metabolic deposition and organic load by a large number of live fishes at $T_2$ were also responsible for a higher concentration of $NH_3$-N and this finding was in accordance with the observation of Razzak et al. [44]. The increased level of $PO_4$-P and $NO_3$-N might be due to higher survival of fish, which may produce fecal materials and other bio perturbation effects in the waterbody [44]. It was estimated that amount of faecal waste roughly ranges between 0.2 to 0.5 kg dry matter per kg feed [45]. Therefore, sludge from fish ponds becomes a great source of nitrogen, phosphorus and potassium [46–48]. Similar observation also made by Tsuruta et al. [49] who reported increased $NO_3$-N concentration in rice field due the excretion of fish.

**Table 1.** Water quality parameters of a rice–fish–vegetable culture system (n = 3 for each experiment).

| Variables | Experiment-1 | | | | Experiment-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | *p*-Value | $T_1$ | $T_2$ | $T_3$ | *p*-Value |
| Temperature (°C) | $31.15 \pm 0.13^a$ | $31.27 \pm 0.05^a$ | $31.22 \pm 0.03^a$ | 0.563 | $31.27 \pm 0.06^a$ | $31.22 \pm 0.03^a$ | $31.25 \pm 0.05^a$ | 0.355 |
| Transparency (cm) | $20.67 \pm 0.29^c$ | $17.92 \pm 0.29^a$ | $19.40 \pm 0.32^b$ | 0.001 | $19.75 \pm 0.25^b$ | $17.83 \pm 0.14^a$ | $19.50 \pm 0.50^a$ | 0.023 |
| pH | $7.25 \pm 0.04^a$ | $7.15 \pm 0.05^a$ | $7.25 \pm 0.04^a$ | 0.452 | $7.18 \pm 0.05^a$ | $7.14 \pm 0.11^a$ | $7.18 \pm 0.07^a$ | 0.427 |
| DO (mg/L) | $5.25 \pm 0.01^{ab}$ | $5.30 \pm 0.04^a$ | $5.22 \pm 0.02^b$ | 0.025 | $5.27 \pm 0.06^b$ | $5.38 \pm 0.03^a$ | $5.31 \pm 0.03^{ab}$ | 0.032 |
| Alkalinity (mg/L) | $61.17 \pm 0.19^a$ | $61.46 \pm 0.50^a$ | $61.21 \pm 0.26^a$ | 0.362 | $60.79 \pm 0.32^a$ | $61.34 \pm 0.32^a$ | $60.81 \pm 0.29^a$ | 0.514 |
| $NH_3$-N (mg/L) | $0.09 \pm 0.00^c$ | $0.14 \pm 0.00^a$ | $0.11 \pm 0.00^b$ | 0.021 | $0.09 \pm 0.00^c$ | $0.13 \pm 0.00^a$ | $0.12 \pm 0.00^b$ | 0.002 |
| $PO_4$-P (mg/L) | $0.32 \pm 0.00^c$ | $0.39 \pm 0.00^a$ | $0.35 \pm 0.01^b$ | 0.001 | $0.31 \pm 0.00^c$ | $0.39 \pm 0.00^a$ | $0.34 \pm 0.00^b$ | 0.001 |
| $NO_3$-N (mg/L) | $1.65 \pm 0.00^c$ | $1.82 \pm 0.01^a$ | $1.73 \pm 0.07^b$ | 0.002 | $1.67 \pm 0.00^c$ | $1.81 \pm 0.00^a$ | $1.74 \pm 0.00^b$ | 0.000 |

Note: Values are mean ± SD. Values in the same row with different superscript letters are significantly ($p < 0.05$) different separately for experiment-1 and experiment-2. Superscript a, b, c and ab indicate the results of multiple comparison test by DMRT.

### 3.2. Plankton Monitoring

The measured mean cell density ($\times 10^3$ cells/L) of total phytoplankton (chlorophyceae, bacillariophyceae, cyanophyceae and euglenophyceae) and total zooplankton (rotifer, cladocera, copepod and crustacean) populations were divided into four major groups (Table 2). There were significant differences ($p < 0.05$) in the mean cell density of total phytoplankton and total zooplankton among the three treatments in both experiment-1 and experiment-2 with the highest at $T_2$ and the lowest at $T_1$. The dominant group of phytoplankton and zooplankton was chlorophyceae and rotifera in both experiment-1 and experiment-2 during the study period. The bottom-feeding nature of *C. carpio* was responsible for the lower density of phytoplankton and zooplankton at $T_1$, which was formerly noted by Milstein et al. [50]. However, the higher abundance of planktons at $T_2$ of both the experiments can be explained by the contribution of alkalinity, $PO_4$-P and $NO_3$-N. Furthermore, higher filtration by *O. niloticus* at $T_3$ caused moderate enhancement of planktons and it was previously reported by Turker et al. [51].

### 3.3. Growth and Production of Rice

The growth parameters of rice i.e., plant height, number of leaf and numbers of tillers/hills recorded are shown in Figure 3. The average value of these parameters in three treatments for each experiment was compared between the experiments. The highest plant height was recorded in experiment-1 at 120 DAT. The number of leafs per plant and numbers of tillers/hill was highest in experiment-2 at 90 DAT. Differences in growth performance of rice, during the study period, were might be due to the genetic variation, physiological functions and growth characters of these varieties. A similar trend was also reported by Shiyam et al. [52] and Mahamud et al. [53] who reported significant variation in total number of tillers in hybrid rice varieties.

**Table 2.** Variation in the cell density ($\times 10^3$ cells/L) of major groups of phytoplankton and zooplankton.

| Groups | Experiment-1 | | | | Experiment-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | *p*-Value | $T_1$ | $T_2$ | $T_3$ | *p*-Value |
| Chlorophyceae | $8.31 \pm 0.14^{c}$ | $9.62 \pm 0.88^{a}$ | $8.66 \pm 0.05^{b}$ | 0.001 | $8.29 \pm 0.05^{c}$ | $9.50 \pm 0.12^{a}$ | $8.68 \pm 0.05^{b}$ | 0.000 |
| Bacillariophyceae | $3.80 \pm 0.09^{b}$ | $4.52 \pm 0.07^{a}$ | $4.36 \pm 0.02^{a}$ | 0.023 | $3.96 \pm 0.05^{b}$ | $4.47 \pm 0.02^{a}$ | $4.50 \pm 0.02^{a}$ | 0.022 |
| Cyanophyceae | $3.17 \pm 0.05^{b}$ | $3.61 \pm 0.07^{a}$ | $3.52 \pm 0.01^{a}$ | 0.032 | $3.14 \pm 0.03^{c}$ | $3.60 \pm 0.05^{a}$ | $3.31 \pm 0.03^{b}$ | 0.001 |
| Euglenophyceae | $0.65 \pm 0.02^{c}$ | $0.76 \pm 0.02^{a}$ | $0.72 \pm 0.00^{b}$ | 0.000 | $0.64 \pm 0.01^{b}$ | $0.74 \pm 0.00^{a}$ | $0.73 \pm 0.00^{a}$ | 0.032 |
| Total phytoplankton | $15.94 \pm 0.1^{c}$ | $18.51 \pm 0.16^{a}$ | $17.25 \pm 0.05^{b}$ | 0.000 | $16.03 \pm 0.06^{c}$ | $18.29 \pm 0.06^{a}$ | $17.13 \pm 0.08^{b}$ | 0.000 |
| Rotifera | $2.59 \pm 0.03^{b}$ | $2.90 \pm 0.15^{a}$ | $1.76 \pm 0.02^{ab}$ | 0.021 | $2.61 \pm 0.04^{b}$ | $2.98 \pm 0.01^{a}$ | $2.92 \pm 0.03^{a}$ | 0.025 |
| Cladocera | $1.58 \pm 0.02^{c}$ | $1.74 \pm 0.02^{a}$ | $1.66 \pm 0.07^{b}$ | 0.000 | $1.56 \pm 0.00^{c}$ | $1.72 \pm 0.00^{a}$ | $1.63 \pm 0.01^{b}$ | 0.001 |
| Copepoda | $1.45 \pm 0.00^{b}$ | $1.54 \pm 0.00^{a}$ | $1.52 \pm 0.00^{a}$ | 0.036 | $1.44 \pm 0.00^{b}$ | $1.53 \pm 0.01^{a}$ | $1.50 \pm 0.00^{a}$ | 0.031 |
| Crustacean | $0.72 \pm 0.00^{b}$ | $0.76 \pm 0.00^{a}$ | $0.73 \pm 0.01^{ab}$ | 0.042 | $0.72 \pm 0.00^{b}$ | $0.76 \pm 0.00^{a}$ | $0.75 \pm 0.02^{a}$ | 0.009 |
| Total zooplankton | $6.35 \pm 0.04^{c}$ | $6.94 \pm 0.15^{a}$ | $6.67 \pm 0.03^{b}$ | 0.000 | $6.34 \pm 0.04^{c}$ | $6.99 \pm 0.03^{a}$ | $6.80 \pm 0.05^{b}$ | 0.001 |

Note: Values are means ± SD. Values in the same row with different superscript letters are significantly ($p < 0.05$) different separately for experiment-1 and experiment-2. Superscript a, b, c and ab indicate the results of multiple comparison test by DMRT.

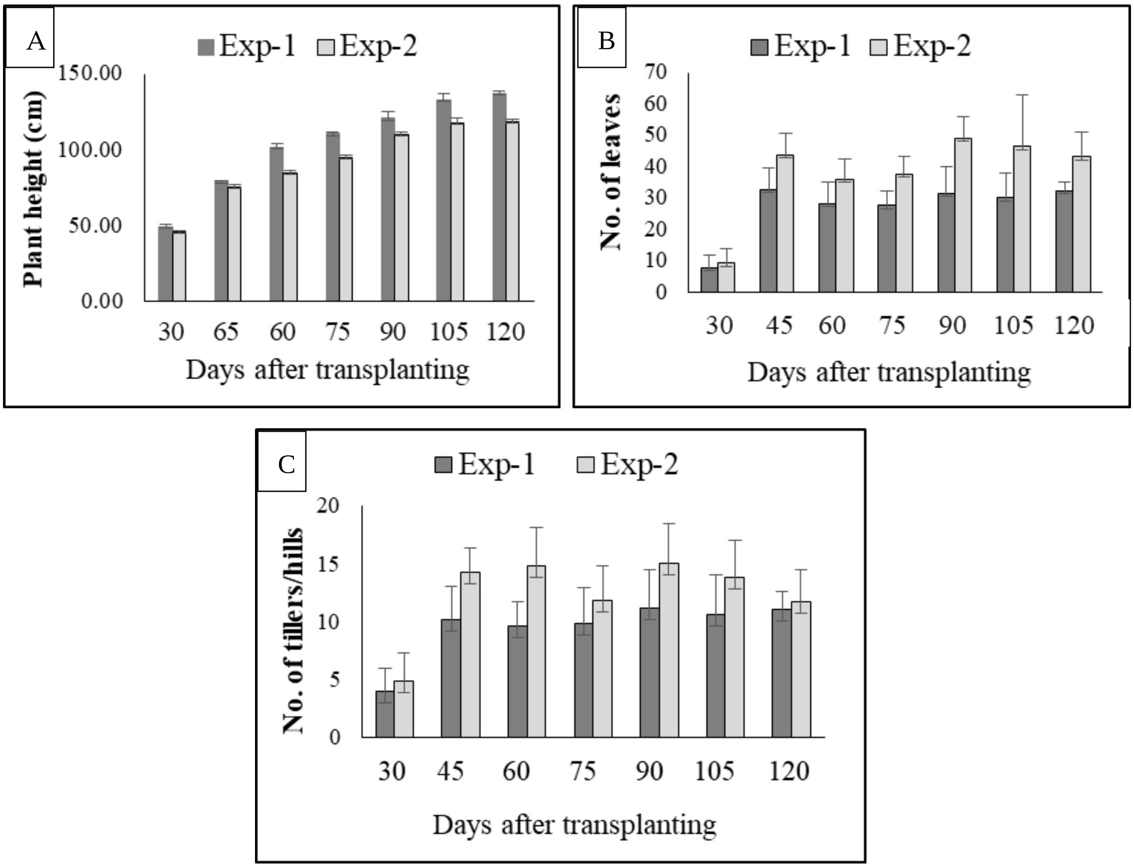


**Figure 3.** Rice growth parameters as characterized by (**A**). plant height, (**B**). no. of leaves and (**C**). no. of tillers/ hills in experiment-1 and 2 of a rice–fish–vegetable culture system. Values are means ± SD.

The yield parameters of rice and straw production are given in Table 3. There was no significant difference among the treatments in each experiment, but there were significant differences between the experiments (varieties) in rice and straw yield parameters. It was observed from paired *t*-test between the treatments of two experiments, the highest grain yield was obtained from treatment $T_3$ in experiment-1 and the lowest from treatment $T_1$ in experiment-2. Varieties also had a significant difference in straw yield (t/ha), with the highest yield at $T_3$ of experiment-1 and lowest in $T_1$ of experiment-2. Among the varieties studied, BRRI-52 produced significantly higher biological yield at $T_3$ and lower for BRRI-51 in $T_1$. Harvest index differed significantly due to the significant differences of the studied varieties. The highest harvest index (%) was found at $T_1$ of experiment-1 and lowest at $T_3$ of experiment-2. Total grains per panicle are also significantly influenced by varieties except for $T_1$. The highest number of grains per panicle was observed at $T_3$ of experiment-1 and the lowest at $T_3$ of experiment-2.

**Table 3.** Comparison of rice and straw yield parameters under different treatments in the rice–fish–vegetable culture system.

| Rice and Straw Yield Parameters | Treatments | Experiment-1 (BRRI-52) | Experiment-2 (BRRI-51) | *t*-Value | *p*-Value |
|---|---|---|---|---|---|
| Grain yield (t/ha) | $T_1$ | 6.36 ± 0.04 | 5.10 ± 0.08 | 54.560 *** | 0.000 |
| | $T_2$ | 6.34 ± 0.05 | 5.38 ± 0.06 | 109.232 *** | 0.000 |
| | $T_3$ | 6.50 ± 0.36 | 4.93 ± 0.04 | 8.573 * | 0.013 |
| Straw yield (t/ha) | $T_1$ | 9.36 ± 0.08 | 8.52 ± 0.09 | 9.018 * | 0.012 |
| | $T_2$ | 9.52 ± 0.02 | 9.19 ± 0.04 | 11.241 ** | 0.008 |
| | $T_3$ | 9.62 ± 0.01 | 8.85 ± 0.04 | 29.103 *** | 0.001 |
| Biological yield (t/ha) | $T_1$ | 15.71 ± 0.12 | 13.62 ± 0.06 | 27.271 *** | 0.001 |
| | $T_2$ | 15.86 ± 0.06 | 14.56 ± 0.03 | 55.429 *** | 0.000 |
| | $T_3$ | 16.12 ± 0.35 | 13.78 ± 0.07 | 14.128 ** | 0.005 |
| Harvest index (%) | $T_1$ | 40.45 ± 0.09 | 37.43 ± 0.56 | 8.351 * | 0.014 |
| | $T_2$ | 39.98 ± 0.15 | 36.90 ± 0.32 | 28.475 *** | 0.001 |
| | $T_3$ | 40.30 ± 1.33 | 35.76 ± 0.10 | 6.373 * | 0.024 |
| Total no. of grains/panicle | $T_1$ | 254.00 ± 78.63 | 240.00 ± 67.45 | −0.195 | 0.863 |
| | $T_2$ | 273.33 ± 8.33 | 203.00 ± 31.58 | −3.094 | 0.091 |
| | $T_3$ | 301.67 ± 7.64 | 199.00 ± 21.52 | −6.598 * | 0.022 |

Note: Values are means ± SD. Figures in a row bearing common letter(s) do not differ significantly ($p < 0.05$). *** $p < 0.05$, ** $p < 0.01$, * $p < 0.001$.

Overall, a significant difference ($p < 0.05$) was observed in the mean values of rice and straw production among the treatments of both experiments (Table 4). The highest rice yield was found at $T_3$ followed by $T_1$ and $T_2$ in experiment-1. The straw yield was also highest at $T_3$ and the lowest at $T_1$. In experiment-2, the highest yield of rice was 5.38 ± 0.06 t/ha at $T_2$ and the lowest at $T_1$, while straw production was also highest at $T_2$ and the lowest at $T_3$. Significant difference in rice yield parameters observed among the experiments might be due to the rice varieties and their growth performance. Previous studies have reported that higher number of effective tillers/hill and a higher number of grains/panicles produced higher grain yield/ha, which supported the findings of the present study [52,54–56].

Vegetable production was highest at $T_1$ and the lowest at $T_2$ of experiment-1. In experiment-2, the highest production of vegetables was also found at $T_1$ and the lowest at $T_3$. However, vegetable production was not varied significantly ($p < 0.05$) among the treatments of both experiments.

**Table 4.** Comparison of rice, straw and vegetable production of the culture systems (1 ha rice field and 120 days of experimental duration).

| Parameters | Experiment-1 | | | | Experiment-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | *p*-Value | $T_1$ | $T_2$ | $T_3$ | *p*-Value |
| Rice (t/ha) | $6.36 \pm 0.04^a$ | $6.34 \pm 0.05^a$ | $6.50 \pm 0.36^a$ | 0.524 | $5.10 \pm 0.08^a$ | $5.38 \pm 0.06^a$ | $4.93 \pm 0.04^a$ | 0.444 |
| Straw (t/ha) | $8.36 \pm 0.08^a$ | $8.52 \pm 0.02^a$ | $8.62 \pm 0.01^a$ | 0.632 | $7.85 \pm 0.04^a$ | $7.79 \pm 0.04^a$ | $7.52 \pm 0.09^a$ | 0.528 |
| Vegetables (kg/ha) | $57.23 \pm 1.24^a$ | $54.31 \pm 1.90^a$ | $54.32 \pm 0.99^a$ | 0.425 | $67.17 \pm 2.29^a$ | $65.59 \pm 3.71^a$ | $64.98 \pm 1.74^a$ | 0.234 |

Note: Values are means ± SD. The letter 'a' used to denote 'no significant difference'. Values in the same row with different superscript letters are significantly ($p < 0.05$) different separately for experiment-1 and experiment-2. Superscript a indicates the results of multiple comparison test by DMRT.

### 3.4. Fish Growth Performance and Yield

The mean values of growth parameters and yield of fishes in different treatments under experiment-1 and experiment-2 were tabulated (Table 5). All the growth parameters (final weight, weight gain, survival rate and SGR) in both experiment-1 and experiment-2 were higher at $T_2$. Significantly higher ($p < 0.05$) higher gross and net production (kg/ha) were also recorded at $T_2$. In both experiments, the best performance of fishes was observed at $T_2$ whereas the cultured species was *B. gonionotus* followed by $T_3$ (*O. niloticus*) and $T_1$ (*C. carpio*). Coche [57] and Vincke et al. [58] pointed out that the fishes suitable for rizi-pisciculture must tolerate (grow) in shallow water, high temperature and low oxygen and high turbidity that are often present in the rice fields on hot days. The suitable fish species must have also the capacity to grow faster to reach the marketable size and must be capable of living in an enclosed field. Siddik et al. [59] mentioned that Tilapia can tolerate environmental extremity very well and can reproduce easily; whereas survival and flesh taste of Common carp is objectionable by the consumer. In the other words, silver barb usually has excellent survival in rice fields and shows good recovery in final harvest. In the present experiments, growth performance and yield of Silver barb were higher compared to Tilapia and Common carp. Survival rate was also higher for Silver barb compared to Tilapia and Common carp. Furthermore, schooling behavior of Tilapia made them vulnerable to predators like snake and larger frog, which reduced their survival rate in the present experiment. However, higher survival of Silver barb compared to Tilapia and Common carp was also reported previously by Frei et al. [40] and Islam et al. [60]. Total yield obtained by Silver barb was higher compared to Tilapia and Common carp in the both experiments. Uddin [61] obtained a fish yield of 245 kg/ha using silver barb and 143 kg/ha using Tilapia, which were lower than the findings of the present study, but agreed in the sense that Silver barb performed better than Tilapia in rice field culture system. Although Tilapia showed better growth performance than that of Common carp in rice fields [26], the yield of Silver barb was higher than that of Tilapia might be attributed to its higher survival. However, there might be other reasons for reduced growth of Tilapia which needs further study. The limitations of this study include the fact that it was experimentally done with technicians and professionals with knowledge of integrated farming, which may not be appropriate for commercial fish farmers with little to no technical training. Due to time and financial constraints, it was only done for one cycle.

**Table 5.** Growth parameters and yield of fishes under rice–fish–vegetable system.

| Parameters | Experiment-1 | | | | Experiment-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | *p*-Value | $T_1$ | $T_2$ | $T_3$ | *p*-Value |
| Initial weight (g) | $19.56 \pm 1.56^a$ | $19.78 \pm 1.30^a$ | $18.17 \pm 0.38^a$ | 0.528 | $20.58 \pm 2.15^a$ | $19.58 \pm 0.52^a$ | $18.92 \pm 0.57^a$ | 0.425 |
| Final weight (g) | $117.00 \pm 2.29^c$ | $164.33 \pm 0.76^a$ | $133.08 \pm 2.75^b$ | 0.000 | $113.24 \pm 2.63^c$ | $165.77 \pm 2.71^a$ | $133.77 \pm 2.56^b$ | 0.002 |
| Weight gain (g) | $97.44 \pm 3.34^c$ | $144.55 \pm 2.06^a$ | $114.91 \pm 3.12^b$ | 0.001 | $92.65 \pm 3.95^c$ | $146.19 \pm 2.31^a$ | $114.85 \pm 2.77^b$ | 0.000 |
| Survival rate (%) | $67.23 \pm 1.29^c$ | $86.72 \pm 1.30^a$ | $78.33 \pm 0.83^b$ | 0.000 | $64.17 \pm 1.67^c$ | $87.57 \pm 1.29^a$ | $76.94 \pm 1.73^b$ | 0.002 |
| SGR (% $bwd^{-1}$) | $1.44 \pm 0.06^c$ | $1.84 \pm 0.05^a$ | $1.66 \pm 0.03^b$ | 0.000 | $1.38 \pm 0.10^c$ | $1.83 \pm 0.02^a$ | $1.63 \pm 0.20^b$ | 0.000 |
| Yield (kg/ha/4 months) | $387.22 \pm 7.48^c$ | $701.62 \pm 8.14^a$ | $538.53 \pm 5.62^b$ | 0.001 | $363.82 \pm 13.94^c$ | $714.75 \pm 18.99^a$ | $515.49 \pm 21.23^b$ | 0.001 |

Note: Values are means ± SD. Values in the same row with different superscript letters are significantly ($p < 0.05$) different separately for experiment-1 and experiment-2. Superscript a, b and c indicate the results of multiple comparison test by DMRT.

### 3.5. Economics of Experiments

The economics of different treatments of rice-fish-vegetable culture systems were accounted (Table 6). The major variable input costs were mainly fertilizer, labour, seed (Rice + Fish+ vegetable), land preparation, ditch management, post management and land used to cost. The total cost was estimated lower at $T_1$ and higher at $T_2$ in both experiment-1 and experiment-2. The lowest net return (fish, rice, rice straw and vegetable) was obtained from $T_1$ of experiment-2 and the highest (161,044.20 BDT/ha) from $T_2$ of experiment-1. The highest benefit cost ratio (BCR) was observed at $T_2$ (2.38) in experiment-1, whereas the lowest BCR was found at $T_1$ (1.72) in experiment-2. Net return and benefit cost ratio (BCR) varied significantly with the treatments. It reveals the optimum combination of different species in integrated cultivation system for greater economic yield and successive usage of natural resources in certain environment within short period of time. Similar observation was also made by Marques et al. [16] who reported that by vegetable cropping ensures the greatest exploitation of land and preserves an ecological balance.

**Table 6.** Comparison of economic parameters among the treatments of experiment-1 and 2 in a rice–fish–vegetable culture system (1 ha rice field and 120 days of experimental duration).

| Variables | Experiment-1 | | | | Experiment-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | $p$-Value | $T_1$ | $T_2$ | $T_3$ | $p$-Value |
| Variable cost (BDT/ha) | | | | | | | | |
| Fertilizer | 7301.52 | 7301.52 | 7301.52 | - | 7301.52 | 7301.52 | 7301.52 | - |
| Labor | 12,516.89 | 12,516.89 | 12,516.89 | - | 12,516.89 | 12,516.89 | 12,516.89 | - |
| Seed (Rice + Fish+ vegetable) | 17,095.80 | 20,183.30 | 19,140.22 | - | 17,095.80 | 20,183.30 | 19,140.22 | - |
| Land preparation | 9387.67 | 9387.67 | 9387.67 | - | 9387.67 | 9387.67 | 9387.67 | - |
| Ditch management | 798.70 | 798.70 | 798.70 | - | 798.70 | 798.70 | 798.70 | - |
| Post-management cost | 928.72 | 928.72 | 928.72 | - | 928.72 | 928.72 | 928.72 | - |
| Total variable cost | 48,029.30 | 51,116.80 | 50,073.72 | - | 48,029.30 | 51,116.80 | 50,073.72 | - |
| Fixed cost (BDT/ha) | | | | | | | | |
| Land used cost | 14,326.00 | 14,326.00 | 14,326.00 | - | 14,326.00 | 14,326.00 | 14,326.00 | - |
| Total cost | 62,355.30 | 65,442.80 | 64,399.72 | - | 62,355.30 | 65,442.80 | 64,399.72 | - |
| Interest on inputs (4 months) | 2078.51 | 2181.43 | 2146.66 | - | 2078.51 | 2181.43 | 2146.66 | - |
| Total inputs | 64,433.81 | 67,624.22 | 66,546.38 | - | 64,433.81 | 67,624.22 | 66,546.38 | - |
| Financial return (BDT/ha) | | | | | | | | |
| Fish | 58,083.59 $^{c}$ | 82,299.42 $^{a}$ | 71,273.76 $^{b}$ | 0.000 | 55554.43 $^{c}$ | 84129.95 $^{a}$ | 67,345.81 $^{b}$ | 0.000 |
| Rice | 136,668.33 $^{a}$ | 136,310.00 $^{a}$ | 139,750.00 $^{a}$ | 0.245 | 109,578.33 $^{b}$ | 115,598.33 $^{a}$ | 105,923.33 $^{b}$ | 0.015 |
| Straw | 8612.89 $^{a}$ | 8593.29 $^{a}$ | 8604.81 $^{a}$ | 0.325 | 8143.87 $^{a}$ | 7779.90 $^{a}$ | 8092.25 $^{a}$ | 0.314 |
| Vegetables | 1547.24 $^{a}$ | 1465.71 $^{a}$ | 1465.00 $^{a}$ | 0.224 | 2156.70 $^{a}$ | 2113.73 $^{a}$ | 2090.83 $^{a}$ | 0.241 |
| Gross return | 204,912.06 $^{b}$ | 228,668.42 $^{a}$ | 221,093.58 $^{b}$ | 0.035 | 175,433.33 $^{c}$ | 209,621.92 $^{a}$ | 183,452.23 $^{b}$ | 0.000 |
| Net return | 140,478.25 $^{b}$ | 161,044.20 $^{a}$ | 154,547.20 $^{b}$ | 0.024 | 110,999.53 $^{c}$ | 141,997.70 $^{a}$ | 116,905.85 $^{b}$ | 0.001 |
| Benefit–cost ratio (BCR) | 2.18 $^{b}$ | 2.38 $^{a}$ | 2.32 $^{ab}$ | 0.022 | 1.72 $^{b}$ | 2.10 $^{a}$ | 1.76 $^{b}$ | 0.021 |

Note: Values are means. Values in the same row with different superscript letters are significantly ($p < 0.05$) different separately for experiment-1 and experiment-2. Currency values are in Bangladeshi Taka (BDT). 1 USD = 84.91 BDT. Superscript a, b, c and ab indicate the results of multiple comparison test by DMRT.

## 4. Conclusions

In the present study, suitable rice, fish and vegetable combination was assessed for sustainable food production from integrated farming system. Results concluded that, integrated rice-fish-vegetable culture had significant effect on water and plankton productivity. Silver barb showed significantly higher growth and production performance among the fishes studied. BRRI-52 resulted in significantly higher grain yield and harvest index compared to BRRI-51. Although, vegetable production was insignificant between the experimental combinations, higher benefit was incurred from the combination of water spinach and cucumber. However, the present study suggested that the combination of BRRI-52, Silver barb, cucumber and water spinach has the potentiality to provide better economic return from integrated aquaculture-agriculture system. The current study advised carrying out more extensive research on choosing different combinations of fish, vegetables, and rice types.

**Author Contributions:** Conceptualization, M.A.S.J. and M.A.H.; methodology, M.A.H. and M.A.S.J.; software, M.A.H.; M.A.S.J. and M.B.H.; validation, M.B.H., M.A.H.; formal analysis, M.A.H. and M.A.S.J., M.S.I.; investigation, M.A.H.; resources, M.B.H.; data curation, M.S.I.; writing—original draft preparation, M.A.H.; M.A.S.J.; S.M.W.A., M.E.P., M.G.U.A. and M.S.I.; writing—review and editing, M.B.H., M.F.A. and T.A.; supervision, M.A.S.J.; funding acquisition, M.A.H., M.A.S.J., M.F.A. and T.A. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was also funded by the Researchers Supporting Project Number (RSP2023R436), King Saud University, Riyadh, Saudi Arabia.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data are provided in the article.

**Acknowledgments:** This study was partially funded by Universiti Brunei Darussalam under the Faculty/Institute/Center Research Grant (No. UBD/RSCH/1.4/FICBF(b)/2020/029), (No. UBD/RSCH/1.4/FICBF(b)/2021/037) and the FOS Allied Fund (UBD/RSCH/1.4/FICBF(a)/2023). The authors would like to acknowledge the support provided by the Researchers Supporting Project Number (RSP2023R436), King Saud University, Riyadh, Saudi Arabia.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviations

ANOVA—Analysis of variance; AM—Anti meridian; BCR—Benefit–cost ratio; BDT—Bangladeshi Taka; BRRI—Bangladesh rice research institute; cm—Centimeter; DAE—Department of agricultural extension; DAT—Days after transplantation; DO—Dissolved oxygen; Gher— Gher, Bengali for "perimeter," is a fish and prawn enclosure built by altering rice fields by creating higher dikes around the field and digging a canal several feet deep within the periphery to retain water during the dry season; ha—Hectare; kg—Kilogram; MoP—Murate of potash; SD—Standard deviation; SDG—Sustainable development goal; SGR—Specific growth rate; SPSS—Statistical package for social science.

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