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*Research article*

# Integration of vertical floating bed for red amaranth cultivation in low land areas of Bangladesh

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**Abstract:** This study incorporates the design, fabrication, implementation and evaluation of soil-based Vertical Floating Bed (VFB). The VFB has contained six plots in three vertical layers, each layer having vertical distance of 0.61 m. The structural load was calculated and three water barrels were used to maintain stable floating condition. Red Amaranth was grown and the production was evaluated with horizontal farm based on no. of leaves (NoL), stem size (SS), crop weight, crop height (CH), root zone depth and total yield (Y). Statistical analysis showed that there was a significant difference in yield among different layers of VFB with horizontal layer. Most of the considerable yield (NoL 10 nos, CH 0.27 m, SS 12 mm, Y 1.54 kg) was achieved from the top layer of the structure (L1). The lowest production (NoL 7 nos, CH 0.19 m, SS 9 mm, Y 0.83 kg) was found in the bottom layer (L3). The elevation of different layers caused growth variances due to sunlight exposure differences. The study suggested that healthy production will be capable as insect and weed infestation was negligible. It can also be a sustainable method to grow vegetables in low-land areas.

**Keywords:** low land areas; haor areas; frequent floods; vertical floating bed; Red Amaranth cultivation; sustainable technology

## 1. Introduction

Agriculture in the twenty-first century faces numerous challenges. The present food production system has to produce more food and fiber to feed the ever-growing population with a smaller rural labor force, contributing to overall development in the many agriculture-dependent developing third-world countries that are adapting to climate change by adopting more efficient and sustainable production methods.

The world's population, according to the United Nations' most recent estimate, is 7.3 billion and it has grown by 3.3 billion, or more than 90%, in the last four decades [1,2]. Bangladesh, a developing country in Southeast Asia, with a population density of 1021 persons per square kilometer, making it one of the world's most densely inhabited countries. In 2009, the country's population was 147 million, and by 2025, it is predicted to reach 176 million, with a population density of roughly 1200 people per square kilometer [3].

Bangladesh is dealing with a severe issue: food scarcity. Despite the fact that the country has attained food self-sufficiency, a significant portion of the population is food insecure. For a long time, scientists have been attempting to feed Bangladesh's expanding population [4].

According to recent statistical studies, Bangladesh's agricultural land is dwindling. Agricultural land use decreased from 9.37 million hectares to 9.19 million hectares between 1997 and 2017, according to the official datasheet of the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) [5]. Other land use increased from 2.18 million hectares to 2.40 million hectares. This indicates that land transfer from agriculture to non-agriculture is increasing at an exponential rate, posing a threat to the food production system and food security. Because of its location on the Brahmaputra River Delta (also known as the Ganges Delta) and the numerous distributaries that flow into the Bay of Bengal, the country is prone to flooding. Because it is part of such a basin and is less than 5 meters above mean sea level, Bangladesh faces the cumulative effects of floods caused by water flashing from nearby hills, the accumulation of inflow of water from upstream catchments, and locally heavy rainfall exacerbated by drainage congestion. In Bangladesh, coastal flooding mixed with riverbank breaches is a typical occurrence, and it has a substantial influence on the country's scenery and civilization. Bangladesh's floodplain covers 80% of the country, and it has a long coastline, putting the country at risk of widespread damage on a regular basis. Bangladesh floods about 26,000 square kilometers (10,000 square miles) (roughly 18 percent of the country) every year. During severe floods, the area affected can reach up to 75% of the country [6,7].

The coastal areas of Bangladesh encompass 19 districts that face or are near the Bay of Bengal, with 148 sub-districts, accounting for 32 percent of the country's land area (47,211 square kilometers) and 25.7 percent of the population [8,9,10]. In the south along the Bay of Bengal, Bangladesh has a total of 2.85 million hectares (ha) of coastal and offshore land, with about 0.83 million hectares of arable land located in the coastal and offshore area, including tidal, estuaries, and river floodplains (Noakhali, Barisal, Patuakhali, and western part of Chittagong) [8]. It is known that vegetables are considered one of the most important groups of food crops due to their high nutritive value, with relatively higher yield and higher return. In Bangladesh, the daily per capita availability of vegetables excluding tuber crops is only 52 g against the required amount of 200 g [11]. This gap is the main reason for widespread malnutrition. Unhealthy and unsustainably produced food poses a global risk to people and the planet. More than 820 million people have insufficient food and many more consume an unhealthy diet that contributes to premature death and morbidity. Transformation to healthy diets from sustainable food systems is necessary to achieve the UN Sustainable Development Goals and the Paris Agreement, and scientific targets for healthy diets and sustainable food production are needed to guide a Great Food Transformation [12]. In Bangladesh, more than 60 different types of vegetables of indigenous and exotic origin are grown. In 2016, the total vegetable growing area in the country was about 225,153 hectares (2.47 acres is equal to a hectare), of which 65% were cultivated during winter [13]. Because of frequent flooding in the monsoon, the farmers have to wait for the winter season so that they can cultivate different types of vegetables as the weather remains dry at that time. To cope with these difficulties and to bring this large amount of low land areas like haor, coastal and offshore areas under cultivation, vertical floating bed cultivation could be a potential solution.

The southern, southwestern, and coastal portions of Bangladesh, on the other hand, are inundated for significant periods every year, especially during the monsoon season. Since the time of their forefathers, the people of these territories have relied on agriculture and have practiced a kind of cultivation known as "Vasoman Chash," which translates to "floating agriculture." This type of agricultural activity has been found to have a high production rate. It was found that floating agriculture is a potential local knowledge-based solution that could aid in achieving long-term livelihood stability in vulnerable places such as Bangladesh's waterlogged districts [14].

The intention of vertical floating bed cultivation is to improve the combination of vertical farming with floating bed agriculture. It attempts to achieve food security and broader development goals in the face of rising food demand and a changing climate. Reduced food miles, or the distance traveled by a food product from farm to the consumer via the market, can be quite beneficial. The greater the distance traveled by food; the more greenhouse gas emissions are produced. Food miles serve as a barometer of the environment, society, and economy of food production, all of which have an impact on the city's long-term viability. The vertical floating bed cultivation can reduce the transportation cost and environmental deterioration caused by fossil fuel burning in the whole process. Based on the above proposition, the present study was conducted to design and construct a Vertical Floating Bed for evaluating the growth rate of Red Amaranth in different layers and for comparing the yield production of Red Amaranth in a Vertical Floating Bed with a horizontal farm.

## 2. Materials and Methods

### *2.1. Site selection*

The right selection of the site is critical to the success of a Vertical Floating Bed. The most important factors to consider while choosing the experimental site are high water quality, ease of handling, and optimum solar exposure. In this experiment, the pond adjacent to the university mosque was selected as the experimental site. The latitude and longitude of the experimental site are 24°54'39.1"N 91°54'10.0"E. The horizontal plot was directly next to the pond.

### *2.2. Raw materials*

To construct the Vertical Floating Bed, pipe fittings, steel wire, drum, cork sheet, jute sacks were used as raw materials. Poultry manure (29.87 kg) from a local poultry farm was collected and used as a nutritional supplement during soil preparation. Plant seeds (BARI Lalshak-1) and Urea fertilizer were collected from different locations.

*2.3. Design consideration of the structure*

For experimental purpose, it was decided to use CPVC pipe and pipe fittings to construct the structure. CPVC provides greater durability and sustainability at a reduced cost. A vertical distance of 0.61 m was maintained among each layer because the maximum height of Red Amaranth ranges from 0.19 to 0.39 m [15]. The vertical distance among layers was doubled so that a sufficient amount of light and air could pass or circulate through each layer and the plant growth was not hindered. The soil depth in each layer was kept at 0.1016 m so that most of the herbaceous vegetables could be grown in VFB including Red Amaranth.

By calculating the total load of the structure, it was found that three water drums were required to apply sufficient upward force to float the structure. So, it was decided to use three water drums to float the structure. The structure was tied to a bamboo so that it could not float away by the current. It was tied in such a way that the structure could go up and down with respect to the water level variation.

*2.4. Description of the structure*

Before the experimentation, the vertical floating structure was designed by using computer-aided design software “AutoCAD”. A three-dimensional structure was designed for a better view and precise evaluation of dimensions (Figure 1). The design consisted of three vertical layers, and each layer was divided into two different plots. Three identical water drums were also designed and attached below the structure.

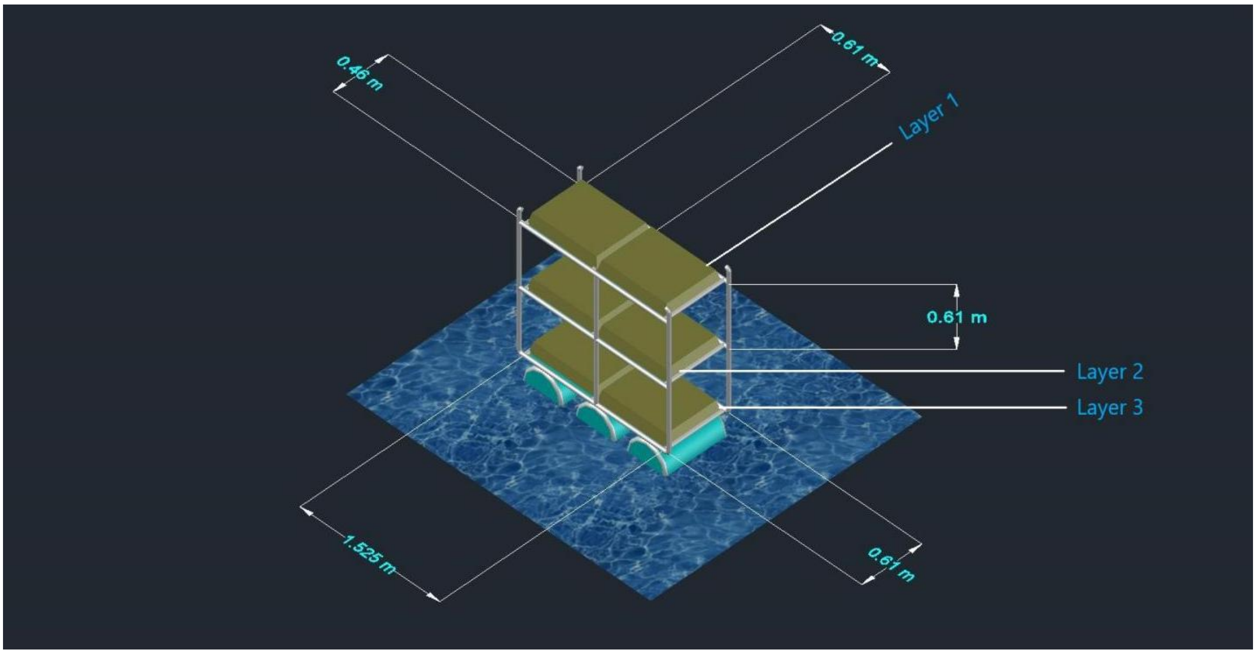



**Figure 1.** Three-dimensional design of the vertical floating bed.

By using CPVC pipe (diameter 0.019 m) and pipe fittings (T, L) the skeleton of the vertical structure was constructed. CPVC solvent cement was used to attach the pipes with the fittings. The bamboos were cut into thin pieces and steel wire was used to adjoin them with the structure. Finally, the cork sheet and jute sacks were used to create the platform which retained the soil. The length of the structure was 1.525 m and the width was 0.61 m. There was a 0.61 m vertical gap among each of the layers. Three water drums, having a capacity of 99 liters each, were attached below the structure which helped the structure to float. A total of 3 structures were made for replication purposes.

*2.5. Soil selection and preparation*

Though a variety of soil types are used for the cultivation of Red Amaranth, loamy and sandy loam soil is most suitable for optimum growth. Sandy loam soil was collected from the horizontal field to maintain the same condition of the soil in both the vertical floating bed and horizontal field. Collected soil (60 kg) was finely prepared and poultry manure (29.87 kg) was mixed properly maintaining the same ratio (Soil:Manure = 2:1) of the horizontal field.

*2.6. Plot preparation*

After soil preparation, the soil was placed on the three vertical layers (Figure 2). Each layer was consisted soil depth of 0.1 m.

**Figure 2.** Prepared plots in the vertical floating bed structure.

2.6.1. Treatments

T1= Red Amaranth production in layer 1 (Top layer of the vertical floating bed).
T2= Red Amaranth production in layer 2 (Middle layer of the vertical floating bed).
T3= Red Amaranth production in layer 3 (Bottom layer of the vertical floating bed).
T4= Red Amaranth production in the horizontal field.

Randomized Complete Block Design (RCBD) was followed with three replications to analyze the data.

*2.7. Load calculation*

The following mathematical equation was used to measure the total load of the structure:

Total load = Weight of empty structure + Soil weight + Irrigation weight + Weight of poultry manure + Estimated yield = 16 kg + 60 kg + 6 kg + 29.87 kg + 4 kg = 115.87 kg = 115.87 kg (1)

The following mathematical equations were used to measure the center of gravity and the buoyancy force of a drum when it was submerged at different levels. It is known that the center of gravity of a circular drum is the midpoint of the axis of the drum that is the middle of the drum.

$$\text{Center of gravity of the drum} = d/2 = 0.401\, m/2 = 0.201\, m \quad (2)$$

Again,

$$\text{Weight of the drum} = W_d = 2.83\, kg \quad (3)$$

Area of the drum,

$$\mathrm{A} = \pi \mathrm{r}^2 = 0.127\, \mathrm{m}^2 \quad (4)$$

Volume of the drum,

$$\mathrm{V} = \mathrm{l} \times \mathrm{A} = 0.635\, \mathrm{m} \times 0.127\, \mathrm{m2} = 0.081\ \mathrm{m}^3 \quad (5)$$

In quarter submerged condition,area of the drum,

$$\mathrm{A}_{1/4} = \mathrm{A}/4 \quad (6)$$

In half-submerged condition, area of the drum,

$$\mathrm{A}_{1/2} = \mathrm{A}/2 \quad (7)$$

In three quarter submerged condition, area of the drum,

$$\mathrm{A}_{3/4} = \mathrm{A} \times 3/4 \quad (8)$$

Volume of the submerged portion,

$$V_s = A_{x/y} \times l \text{ [Here, x/y = submerged condition]} \quad (9)$$

Weight of water displaced,

$$\mathrm{W_w} = \mathrm{V_s} \times \gamma_\mathrm{w} \text{ [Here, } \gamma_\mathrm{w} \text{ = density of water (1000 kg/m3)]} \quad (10)$$

$$\text{Lift, } \mathrm{F} = \mathrm{W_w} - \mathrm{W_d} \quad (11)$$

Lift and Buoyant force are same,

$$F_b = F \quad (12)$$

$$\text{Combined lift} = F_b \times 3 \quad (13)$$

The load calculation of vertical floating bed structure for three different conditions is given in Table 1.

**Table 1.** Calculation of lift for different submerged condition.

| Parameters | For quarter submerged condition | For half-submerged condition | For three quarter submerged condition |
|---|---|---|---|
| Area of the submerged portion | 0.03 $m^2$ | 0.06 $m^2$ | 0.10 $m^2$ |
| Volume of the submerged portion | 0.02 $m^3$ | 0.04 $m^3$ | 0.06 $m^3$ |
| Weight of water displaced | 21 kg | 41 kg | 61 kg |
| Lift | 18.17 kg | 38.17 kg | 58.17 kg |
| Buoyant force (each drum) | 178.07 N | 374.07 N | 570.07 N |
| Combined lift (all 3 drums) | 534.19 N | 1122.19 N | 1710.19 N |

The total weight of the structure was found at 115.87 kg. The drums were submerged at a depth of 0.201 m which indicates that the drums were half submerged. The total lift was found at 114.51 kg (1122.19 N). So, there was an extra weight of 1.36 kg which was later decreased due to the decomposition of organic matter and soil erosion. It was observed that the center of buoyancy and the center of gravity of the drum was coincide with each other. There was no torque about the center of mass due to the buoyancy force. It was neutrally stable. There was no preferred orientation.

### *2.8. System operations and measurements performed*

#### 2.8.1. Plant materials

In this study, a high-yielding variety of Red Amaranth (*Amaranthus gangeticus*), "BARI Lalshak-1" was cultivated. The variety was released by Olericulture Division, Horticulture Research Center (HRC), BARI in 1996. It is an all-year-round crop having an approximate yield rate of 12-14 ton/ha [16]. This variety is tolerant to common insect pests and diseases and it is a short duration crop (30-40 days) [17]. The leaves and seeds of Red Amaranth are nutritionally dense and are a good source of dietary fiber, Calcium, and Iron. The seeds are also high in protein.

#### 2.8.2. Seeding

A total of 30 grams seed was collected and broadcasted in three layers while 10 grams seed was broadcasted in the horizontal field. Seeds were covered by topsoil to create favorable conditions for proper germination.

#### 2.8.3. Irrigation

Irrigation water was applied according to the requirements. A bottle of 1-liter capacity was used to measure the same amount of water and applied two times a day in each layer.

#### 2.8.4. Collection of crop data

From each plot, 10 crops were picked randomly, the number of leaves, height, weight, stem size, and root depth of each plant were measured. Then the average number of leaves, height, weight, stem size, and root depth were calculated by using those individual data. The weight was measured using an electric precision balance (AND Electronic Precision Balance, Model: EK 600i, Manufacturer: A&D, Japan). Crop length and root depth were measured using a centimeter stainless scale. Measuring tape was used to measure the stem size of the plant. The total harvested crop weight of each plot was also measured using electric balance.

#### 2.8.5. Collection of sunlight intensity data

The sunlight intensity data was recorded in Klux (Kilo Lux) using CEM DT 1308 light meter (Manufacturer: CEM, China). The data were obtained from the middle of each layer.

#### 2.8.6. Collection of soil nutrient data

The soil sample of Vertical Floating Bed was collected before placing the seeds and after harvesting to investigate the soil nutrient status at the respective time. These samples were analyzed in the laboratory of Soil Resource Development Institute (SRDI), Sylhet.

### *2.9. Comparison yield view*

The comparative study was investigated in Vertical Floating Bed and Horizontal farming system with respect to different yield parameters (Figure 3).

**Figure 3.** Pictorial view of yield in VFB and horizontal farm.

### *2.10. Economic calculation*

In this experiment, an unused water body was used to cultivate Red Amaranth, where traditional farming was not possible. Using Vertical Floating Bed technology, the crop was cultivated in three vertically stacked layers which were enabled to obtain three times more yield than that of horizontal traditional land farming without using any land surface.

The annual cost of operation of the Vertical Floating Bed was computed as the sum of fixed costs (FC) and variable costs (VC).

Fixed cost was determined by using the capital consumption method. Capital Consumption (CC) was calculated by equation as follows (Hunt, 1995).

$$CC = (P - S)\, CRF + Si \tag{14}$$

$$\text{Capital Recovery Factor (CRF)} = \{i(1+I)^L\}/\{(1+I)^{L-1}\} \tag{15}$$

**Table 2.** Calculation of gross margin of vertical floating bed.

| Purchase price (P) | 12000 Taka |
|---|---|
| Salvage value (S = 10% of P) | 1200 Taka |
| Number of years (L) | 20 years |
| Interest rate (i) | 9% |
| Capital Recovery Factor (CRF) | 0.11 |
| Fixed Cost (CC) | 1296 Taka |
| Operator and Labor cost (OLc) | 500 Taka |
| Repair and Maintenance cost (RMc) | 500 Taka |
| Variable Cost (OLc + RMc) | 1000 Taka |
| Total cost per year | 2296 Taka |
| Total cost per cultivation season (TC) | 189 Taka |
| Total revenue (TR) | 200 Taka |
| Gross margin (TR - TC) | 11 Taka |

Note: 1 Taka (Tk.) = 0.012 US Dollar (USD).

### *2.11. Statistical analysis*

Statistical analysis was done using the software "Statistix 10". Randomized Complete Block Design (RCBD) and LSD (Least Square Difference) all-pairwise comparison test was followed to analyze the data. Yield production was analyzed in terms of height of crop, number of leaves, and stem size.

## 3. Results

### *3.1. Growth rate of the plant*

Figure 4 shows that the maximum height of the plant was 0.27 m, found in layer 1 and layer 2. In layer 2 and 3, the maximum plant height was found at around 0.25 m and 0.24 m respectively. The result shows that the growth of layer 1 was the highest among other layers. The difference in the growth might happen due to the variation of the sunlight among different layers.

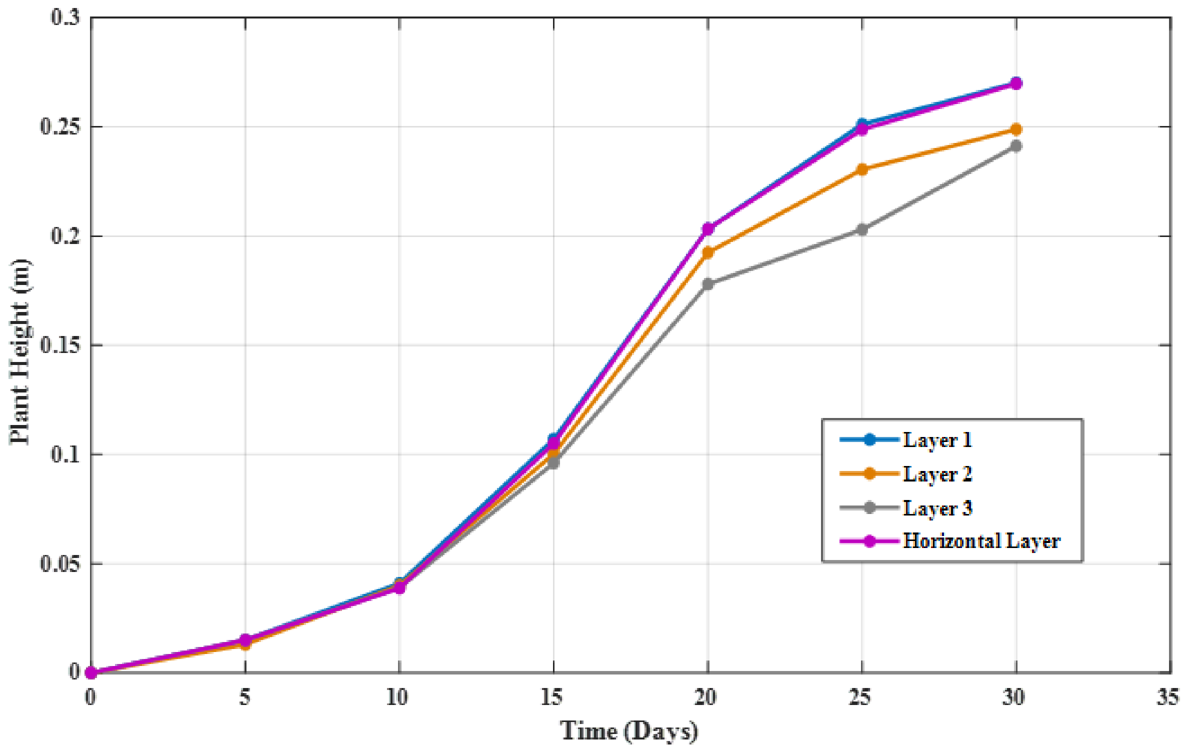



**Figure 4.** Growth rate of Red Amaranth in different layers.

### *3.2. Comparison of Red Amaranth yields*

It is necessary to investigate both the horizontal farming system and the vertical floating farming system to understand the sustainability of the vertical floating farming system. The yield received from both farming systems should be compared concerning the number of leaves, the height of the plant, the weight of the plant, and the root zone depth of the plant. As the vertical floating farming system consists of three vertical layers, the total farm area of the vertical floating farming system is three times greater than the horizontal farming system.

It was seen that if the same growing medium was provided, one layer of the vertical floating farming system could produce more or less the same amount of Red Amaranth (1.54 kg) as the horizontal layer production (1.34 kg). It was observed that the yield of the second layer (1.25 kg) and the third layer (0.83 kg) was less due to the lack of sunlight. Thus, the combined yield of the three layers is higher than that of the horizontal layer.

Crop data like the number of leaves per crop, height, root depth, stem size, and weight of crop was measured and their averages were calculated. It was observed that the vertical floating farming system showed better results than the horizontal farming system (Figure 5).

### *3.3. Result of statistical analysis*

In the statistical analysis, T1, T2, T3, and T4 represent Layer 1, 2, 3, and the horizontal layer respectively. The null hypothesis represents that no difference in crop parameters among 4 layers. After getting the AOV/ANOVA (Analysis of Variance) table, the p-value showed us the level of significance of our analyzed data. The P-value, or probability value, usually tells us how likely it is that our data could have occurred under the null hypothesis. The F value is a value on the F distribution. The value can be used to determine whether the test is statistically significant. If the null hypothesis is true, it is expected that the F to have a value close to 1.0 most of the time. A large F ratio means that the variation among group means is more than we'd expect to see by chance. In ANOVA, mean squares are used to determine whether factors (treatments) are significant. The treatment mean square is obtained by dividing the treatment sum of squares by the degrees of freedom. The treatment mean square represents the variation between the sample means. The coefficient of variation (CV) is a measure of relative variability. It is the ratio of the standard deviation to the mean (average).

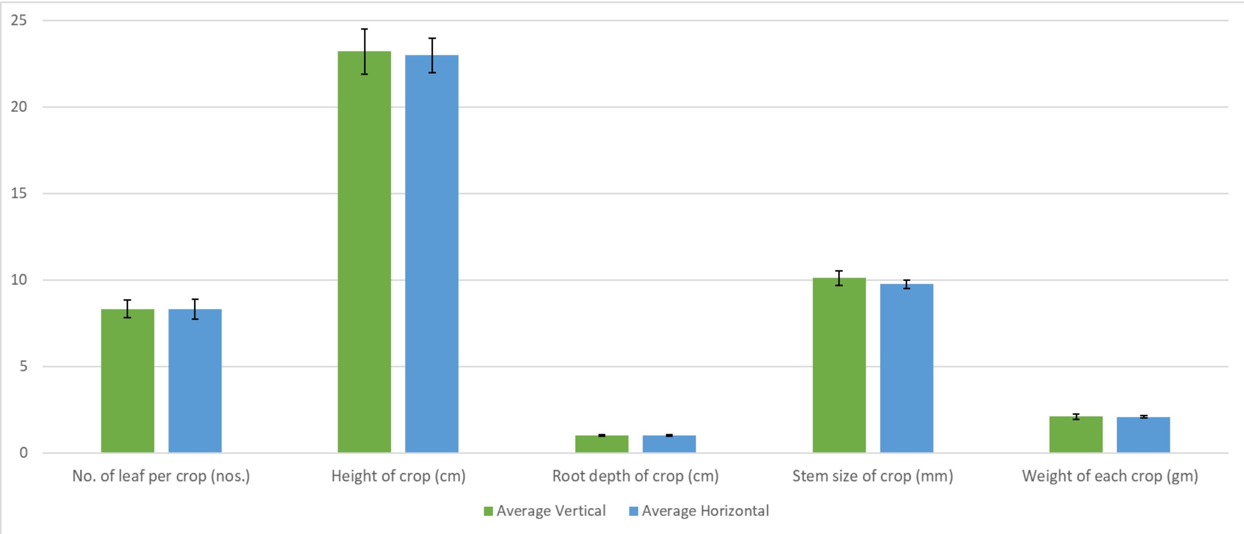



**Figure 5.** Comparison of different plant parameters between VFB and horizontal farm.

**Table 3.** Randomized complete block AOV/ANOVA for the height of crop.

| Source | Degree of Freedom (DF) | Sum of Square (SS) | Mean Square (MS) | F (F variation) | P (Probability Value) |
|---|---|---|---|---|---|
| Replication | 2 | 4.667E-04 | 2.333E-04 | | |
| Treatment | 3 | 7.000E-04 | 2.333E-04 | 3.50 | 0.0896*** |
| Error | 6 | 4.000E-04 | 6.667E-05 | | |
| Total | 11 | 1.567E-03 | | | |
| Grand Mean | 0.2317 | Coefficient of variation (CV) | 3.52 | | |

Note: ***denotes the result was not significant at 5% level.

The value of P shows that the result was not significant, so the null hypothesis was accepted. There was no significant difference in terms of crop height among different layers as shown in Table 3. The critical value for comparison of no. of leaves is 1.6313.

**Table 4.** Randomized complete block AOV/ANOVA for no. of leaves.

| Source | Degree of Freedom (DF) | Sum of Square (SS) | Mean Square (MS) | F (F variation) | P (Probability Value) |
|---|---|---|---|---|---|
| Replication | 2 | 1.16667 | 0.58333 | | |
| Treatment | 3 | 0.25000 | 0.08333 | 0.33 | 0.8022*** |
| Error | 6 | 1.50000 | 0.25000 | | |
| Total | 11 | 2.91667 | | | |
| Grand Mean | 8.4167 | Coefficient of variation (CV) | 5.94 | | |

Note: ***denotes the result was not significant at 5% level.

The value of P shows that the result was not significant, so the null hypothesis was accepted. There was no significant difference in terms of no. of leaves among different layers as shown in Table 4. The critical value for comparison of no. of leaves is 0.9989.

**Table 5.** Randomized complete block AOV/ANOVA for yield.

| Source | Degree of Freedom (DF) | Sum of Square (SS) | Mean Square (MS) | F (F variation) | P (Probability Value) |
|---|---|---|---|---|---|
| Replication | 2 | 0.07215 | 0.03608 | | |
| Treatment | 3 | 0.62217 | 0.20739 | 23.14 | 0.0011** |
| Error | 6 | 0.05378 | 0.00896 | | |
| Total | 11 | 0.7481 | | | |
| Grand Mean | 1.165 | Coefficient of variation (CV) | 8.13 | | |

Note: **denotes the result was significant at 5% level.

The value of P shows that the result was significant, so the null hypothesis was rejected. There was significant difference in terms of yield among different layers as shown in Table 5. The critical value for comparison of yield is 0.1892.

**Table 6.** Randomized complete block AOV/ANOVA for stem size.

| Source | Degree of Freedom (DF) | Sum of Square (SS) | Mean Square (MS) | F (F variation) | P (Probability Value) |
|---|---|---|---|---|---|
| Replication | 2 | 0.45542 | 0.22771 | | |
| Treatment | 3 | 0.62062 | 0.20687 | 3.30 | 0.0995*** |
| Error | 6 | 0.37625 | 0.06271 | | |
| Total | 11 | 1.45229 | | | |
| Grand Mean | 10.071 | Coefficient of variation (CV) | 2.49 | | |

Note: *** denotes the result was not significant at 5% level.

The value of P shows that the result was not significant, so the null hypothesis was accepted. There was no significant difference in terms of stem size among different layers as shown in Table 6.

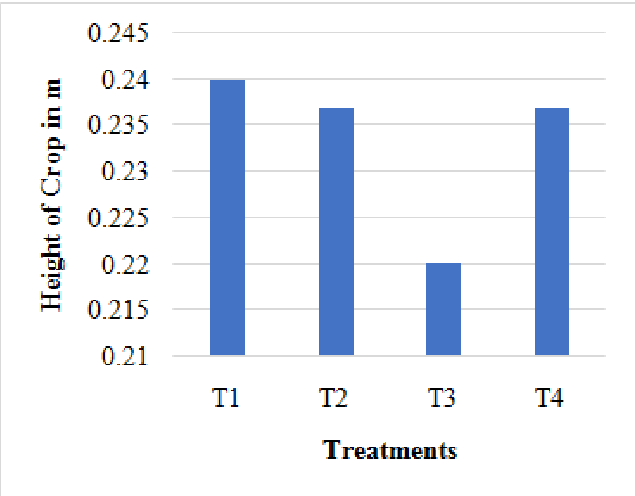
The critical value for comparison of stem size is 0.4747.

The mean value of different collected crop parameters was found from the LSD all-pairwise test as shown in Table 7. Figures 6 and 7 represent the height, no. of leaf, yield and stem size graphically with respect to mean values of statistical analysis from LSD test.

**Table 7.** Means of all crop parameters for treatments.

| Treatment | Height (m) | No. of leaf (nos) | Yield (kg) | Stem size (mm) |
|---|---|---|---|---|
| T1 | 0.24 (a) | 8.7 (a) | 1.46 (a) | 10.40 (a) |
| T2 | 0.237 (a) | 8.3 (a) | 1.19 (b) | 10.15 (ab) |
| T3 | 0.22 (b) | 8.3 (a) | 0.82 (c) | 9.80 (b) |
| T4 | 0.237 (ab) | 8.3 (a) | 1.18 (b) | 9.93 (b) |
| % of CV value | 3.57 | 5.34 | 8.13 | 2.49 |
| Level of significance | NS | NS | S | NS |

Note: CV = Coefficient of variation.



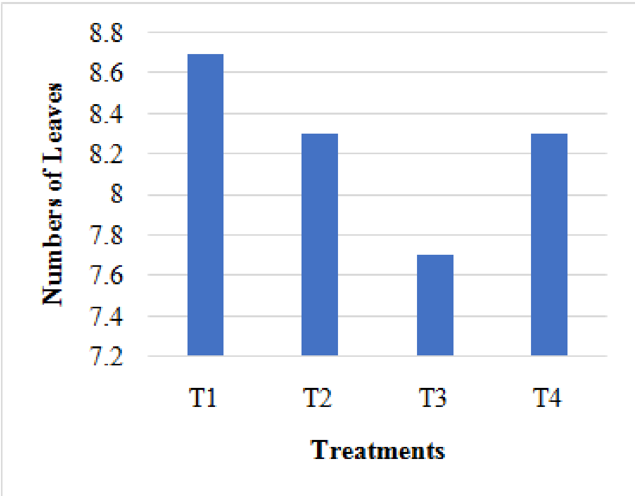




**Figure 6.** The mean value of height and number of leaves for different treatments.

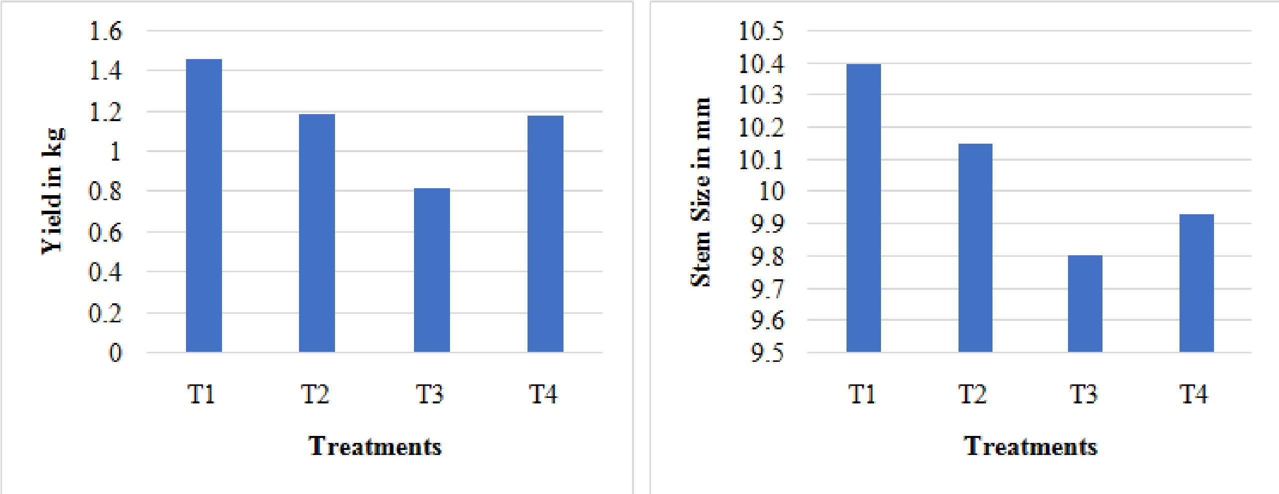



**Figure 7.** The mean value of yield and stem size for different treatments.

From the statistical analysis of Sunlight intensity data (Random Complete Block AOV Table for Sunlight intensity per hour), it was found that there was a significant difference in sunlight intensity among the layers all day long except the sunlight intensity of 3:38 pm and 4:38 pm (Table 8). Because the p values for 3:38 pm (0.4144) and 4:38 pm (0.077) were greater than the alpha value of 0.05.

**Table 8.** Means of sun light intensity (klux) for treatments.

| Treatment | 6:38 AM | 7:38 AM | 8:38 AM | 9:38 AM | 10:38 AM | 11:38 AM |
|---|---|---|---|---|---|---|
| T1 | 2.4167 (a) | 12.227 (a) | 13.873 (a) | 25.05 (a) | 72.81 (a) | 67 (a) |
| T2 | 0.915 (c) | 5.513 (b) | 6 (c) | 8.077 (b) | 9.753 (b) | 56.39 (b) |
| T3 | 1.59 (b) | 5.39 (b) | 7.65 (b) | 7.15 (b) | 9.82 (b) | 43.927 (c) |
| T4 | 2.4167 (a) | 12.227 (a) | 13.877 (a) | 25.05 (a) | 72.81 (a) | 67 (a) |
| % of CV value | 1.38 | 0.72 | 0.58 | 17.81 | 3.32 | 3.46 |
| Level of significance | S | S | S | S | S | S |
| Treatment | 12:38 PM | 1:38 PM | 2:38 PM | 3:38 PM | 4:38 PM | 5:38 PM |
| T1 | 64.42 (a) | 56.247 (a) | 40.873 (a) | 17.927 (a) | 9.27 (a) | 0.43 (a) |
| T2 | 51.21 (b) | 44.077 (b) | 33.317 (b) | 21.337 (a) | 0.9367 (a) | 0.19 (b) |
| T3 | 48.927 (c) | 43.54 (b) | 31.977 (c) | 20.4 (a) | 0.65 (a) | 0.2133 (b) |
| T4 | 64.42 (a) | 56.247 (a) | 40.873 (a) | 17.927 (a) | 9.24 (a) | 0.43 (a) |
| % of CV value | 1.35 | 5.28 | 0.06 | 14.73 | 86.35 | 4.57 |
| Level of significance | S | S | S | NS | NS | S |

Note: CV = Coefficient of Variation.

Sunlight intensity data of both T1 (first layer of VFB) and T4 (Horizontal layer) was identical because there was no obstacle to block the sunlight from falling on both layers. And the intensity of sunlight at both layers was the same as they experienced open sunlight (Figure 8).

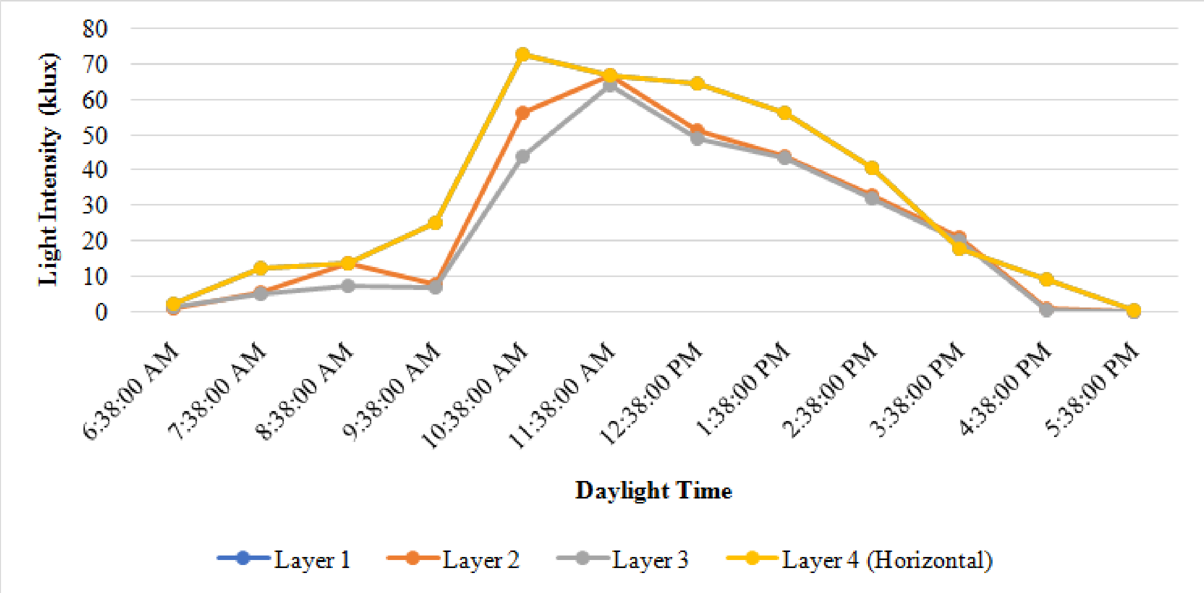



**Figure 8.** Graphs for means of sunlight intensity for treatments.

### *3.4. Soil Nutrient Status*

Due to the absorption of nutrients from the soil by plants, extensive changes in soil nutrition were observed after harvesting (Table 9). The application of poultry manure and the depletion of ammonia-based nitrogen and sulfur minerals in the soil increased the soil pH [18,19]. The mechanism responsible for this increase in pH was due to ion exchange reactions which occur when terminal $OH^{-}$ of Al or $Fe^{2+}$ hydroxyl oxides are replaced by organic anions which are decomposition products of the manure such as malate, citrate, and tartrate [20–23]. The presence of more organic matter in the soil accelerated mineral weathering, which increased the potassium levels and the decomposition of the organic matter also increased the level of phosphorus in the soil [24,25]. It is known that after cultivating crops in a land, there would be a shortage of organic matter in the soil which had also been observed here [26].

**Table 9.** Soil nutrient status of two different stages.

| | pH | OM | N | K | P (Bray) | S |
|---|---|---|---|---|---|---|
| | | % | | Meq/100 g soil | Mg/kg (ppm) | |
| Soil sample before planting | 5.8 | 3.77 | 0.19 | 1.36 | 94.10 | 74 |
| Soil sample after harvesting | 6.1 | 3.03 | 0.16 | 2.65 | 191.96 | 65 |

## 4. Discussion

Vertical Floating Bed (VFB) is a modern agricultural technology that is used to cultivate crops on a floating structure, on standing water containing several layers which are called Beds. According to governmental statistics, in 2019, around 0.677 million hectares of croplands were damaged by the flood that affected about 6.1 million people in 28 districts. Crops of 0.532 million hectares were destroyed and the rest damaged [27]. Due to being a flood-prone region, this kind of damage happens quite regularly. Apart from flooding, farmers are facing some serious problems obtaining cultivable lands due to land shortage. These problems can be mitigated by using the help of vertical floating farming system which can save their valuable crops from getting spoilt. Farmers can utilize this facility to produce seedlings. It was observed that just a few studies on soil-based vertical floating beds had been carried out. Though numerous studies on vertical farming, which is quite similar to vertical floating bed technology, have been conducted. Tawhidul Islam et al. [28] looked into floating bed farming, which has shown to be an effective method of agricultural crop production in a variety of wetland environments across the world. Researchers discovered that vegetables, flowers, and seedlings were produced in freshwater lakes and marshes in Bangladesh utilizing this floating farming approach, which required no extra irrigation or artificial fertilizer.

In the present study, it was observed that Red Amaranth growth in VFB system was approximately 3 times greater than the production received from the horizontal farming system (Figure 3). It was seen that if the same growing medium was provided, one layer of the vertical floating farming system could produce more or less the same amount of Red Amaranth (1.54 kg) as the horizontal layer production (1.34 kg). It was also observed that the vertical floating farming system showed better results than the horizontal farming system in terms of measured crop parameters. Due to frequent floods and water salinity concerns, the difference in increased production, even with the lower performance in the shaded layers, encourages the adoption of VFB production systems in low land locations such as Haors, Coastal, and offshore lands.

Different studies compared productivity between horizontal and vertical farming systems and they highlighted higher productivity in the vertical farming system. Al Mamun et al. [29] compared horizontal and vertical farming systems for Red Amaranth. From the vertical farming system, more Red Amaranth yield was achieved compared to the horizontal farming system. At the same time, the quality parameters were different between the systems and the vertical farming system showed better results.

From the study, it was observed that there was a significant difference in sunlight intensity among the layers all day long. The difference in the harvesting weight of plants might happen due to this variation of the sunlight among different layers. Several researchers concluded that appropriate light intensity is important for photosynthesis, as well as for attaining large biomass and the yield of valuable organs [30–32].In a study, Ercan Ozkaynak [33] found that hours of sunlight influence significantly the duration of the vegetation period of field crops. Cabanás et al. [34] investigated that a high amount of light is required to maximize the production of Basil. So, it can be recommended that the sunlight availability should be maintained properly by placing the vertical floating bed in a suitable position to ensure better yield.

In this study, it was found that a profit of Tk. 11 is available in a land of 1.67 $m^2$ of vertical floating bed. Then the estimated profit per hectare will be Tk. 65,868, which is more profitable than traditional horizontal farming. It was found that the gross margin from traditional horizontal farming ranges from Tk. 24,243 to Tk. 30,800 per hectare [35].

VFB can be used to cultivate leafy vegetables all around the year. Small farmers can construct such structures at a very low cost if they use bamboo or wood. Commercial-scale vegetable production can be possible if this structure can be used in large areas.

From the above discussion, it can be concluded that the VFB technology might help to meet the demand for food and could bring prosperity to the poverty-stricken farmer's community in Bangladesh. Farmers living in low-land areas can cultivate vegetable crops that will help them to meet the food crisis and nutritional requirements. Also, the VFB technology can be implemented in the cities, which will meet the rising food demand of the urban population. Kalantari et al. [36] studied the application of Vertical Farming into cities and found that it would simultaneously help to reduce poverty, add to food safety, and increase contextual sustainability and human well-being.

When analyzing the feasibility of creating a vertical floating bed system, various variables must be taken into account when evaluating the information examined and the conclusions achieved in this study. It is critical to determine the most appropriate crop type. The cost of building a vertical floating bed system should also be considered. The depth of the growth media should be determined by the depth of the root zone of the plant. Irrigation water should be properly delivered so that the soil is not carried away. The structure should be protected from the damaging effects of wind and water waves to the greatest extent possible.

## 5. Conclusions

Presently a large portion of the low-lying land and flood-affected regions are mostly unutilized and facing crisis of cultivable land. In this study, Red Amaranth was grown to investigate the different production parameters and sustainability of vertical floating bed compared with horizontal cultivation method. The result showed significant yield differences among the three layers of VFB and the horizontal farming layer due to sunlight availability. This method could be practiced during the waterlogged conditions and in coastal regions because of soil salinity problem to get quality vegetable yield. The vertical floating-bed technique will also bring positive social impacts to meet up the food crisis and nutritional requirements as an economical technology for vegetable cultivation.

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## Conflicts of interest

The authors declare no conflict of interest.

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