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Full Length Research Paper

Production of Red Amaranth in a Vertical Farm and Evaluation of its Sustainability

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World population has grown in the past few decades and will increase considerably in the following ones, especially in urban areas. Continued population growth leads to rapid urbanization which results in a decline in arable land, ongoing global climate change, water shortages and could change our view of traditional farming to highly efficient urban farms. This project encompasses the design, construction, and evaluation of a soil based vertical farm. The vertical farm contained six plots in three vertically layers. Each layer of the vertical farm, was elevated 2 feet higher than the below layers. Red amaranth was grown on the vertical farm to investigate the growing rate and sustainability of red amaranth in vertical farm. Evaluations have been done on the yield production of red amaranth and compared with horizontal farm. Production is compared on the basis of growing time, crop weight, crop length, root zone depth etc. Statistical analysis of the yield production showed that there was significant difference in yield production between different layers, and with horizontal layers. Most quality yields were grown (number of leaves 9, plant height 15 cm, plant weight 3.5 gm) in the uppermost layer of the structure. Lowest yield production (number of leaves 7, height of plant 10cm, weight of plant 1.5gm) was observed in lower layer. The elevation of the different layers did cause a noticeable difference in growth due to variation in light exposure. It was seen that weed infestation was zero. Also, insect infestation was not noticeable. The system was capable of producing high-quality red amaranth. Moreover, the construction of this vertical farm can be done by anyone with reasonable tool experience and the right set of tools. The adaptability of the vertical farm is also expected to increase among the unemployed youth and farmers, entrepreneurs and will generate more employment.

Keywords: Urbanization, urban agriculture, vertical farming, red amaranth, sustainability.

INTRODUCTION

Agriculture is the only reliable source of food from the very beginning of human civilization. But today most daunting task for agricultural sciences is to ensure continuous, enough and quality supply of food for increasing population

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day by day. As a result, cities throughout the world are experiencing a substantial increase in population; this growth is accompanied with a change in food habits and rising concerns for food security. **Now a day's ensuring food security has been a global concern. As of November 2017, about 1.5ha of the globes land surface is used to feed 7.6 billion world population, which is approximately equal to the size of South America (**Despommier,2010)**.** By 2050, the world must feed 9 billion people and the demand for food will be 60% greater than it is today. To confront this increased demand for food, extra 2.1 billion acres of land will have to cultivate, if farming continues to be practiced as it is today. Shortage of water and land resources are major constraints to combat this task. In this regard agriculture, which is the upstream food-producing sector, is, therefore, in need of new and modern methods to ensure the world's food security. As infrastructure taking place, the use of farming land is decreases, forest and grassland is also decreasing so that the biggest adverse effects on climate change such as uneven rainfall, uneven temperature, decreases ground water table etc. like situation occurs. So, the villagers start moving towards town and city at where they can get some money to survive (Bhangaonkar et al. 2017). Therefore, a sustainable modern technique should be introduced to create linkage between urbanization and agriculture. A recent trend in agriculture has introduced known as vertical farming to bring the cities in agricultural crop production to meet the increasing demands of food. By examining issues related to food security, urban population growth, farmland shortages, "food miles" and associated greenhouse gas (GHG) emissions. Urban planners and agricultural leaders have argued that cities will need to produce food internally to respond to demand by increasing population and to avoid paralyzing congestion, harmful pollution, and unaffordable food prices and examines urban agriculture as a solution to these problems by merging food production and consumption in one place, with the vertical farm is suitable for urban areas where available land is limited and expensive (Al-Kodmany, 2018).Generally, vertical Farming (VF), can be defined as a system of farming whereby plants, animals, fungi and other life forms are cultivated for food, fuel, fibre or other products or services by artificially stacking vertically above each other. Vertical farming which means growing food in skyscrapers might help to solve many of these problems like rising population and purchasing power, demand for food and changing consumer preferences are building pressure on our resources. The purpose of this study was to construct a Vertical Farm and thereof investigate the economic feasibility of it. In a concurrent Engineering Study initiated by DLR Bremen, a farm, 37 floors high, was designed and simulated in Berlin to estimate the cost of production and market potential of this technology. It yields about 3,500 tons of fruits and vegetables and ca. 140 tons of tilapia fillets, 516 times more than expected from a footprint area of 0.25 ha due to stacking and multiple harvests (Banerjee, 2013). It is a step ahead technologies from green houses as it involves using of resources in vertical arrays. Vertical farming can be a means of sustainable urban agriculture as a partial solution to the issue of global food insecurity, the development of a sustainable agricultural initiative and also that it holds promise for communities struggling with chronic food security problems (Besthorn, 2012).In vertical farming system plants could be cultivated in three ways in:

A soil-based system in which plants are potted in trays of soil, a hydroponic system in which plants are grown without soil by dipping the roots of plants in water containing nutrients, and an aeroponic system in which the roots of plants are sprayed periodically with a mist that provided the necessary nutrients, hydration, and oxygen for growth (Khoo Hong Meng). Actually, vertical farming maximizes the limited ground spaces which increase the land size so many times. Although the size of the ground space increment determined by the number of vegetable growing beds constructed above the ground. There has been a lot of scepticism and disbelief in the effectiveness and efficiency of vertical farms in cities. Many critics believe it is not affordable or realizable. But recent success in vertical farming disproving these critics by presenting three examples that prove vertical farms are the future, and the dependence for billions of people; as great migration to cites are occurring all over the world. These examples will vary from the large-scale farm buildings to small-scale family farms: Singapore Sky Greens – Greens for Five Million; 1 Million Pounds/3 Acres; Family Farm in the Big City. Authors also described the technological, economic, social, and legal aspects of vertical farming (Duric et al. 2015). The distance which food travels from farm to consumer via market is known as food miles. A weighted average source distance is calculated from the distance and the amount of food transported. The total transport distance is calculated beginning at the farmer's land, then through the food production and trading processes until it reaches the consumer. The greater the distance the food is transported, the greater are the greenhouse gas emissions. Evaluation of food miles can be divided into two categories: food miles in the country and international food miles. Food miles acts as an indicator of the environment, society, and economy of food production, which affect the sustainable development of the city. Vertical farming employs vertical stacking of the farms therefore small land can be utilized for more production. This technique is also well suited for the rapidly growing global urban population as the demands of food supply can be met from within the cities and thus reducing the transportation cost and environment deterioration caused by fuels in the process (Garg et al. 2014).Moreover, the controlled growing conditions will permit a reduction or total abandonment of the use of chemical pesticides, fertilizers, etc. On the other hand, the advantages of vertical farming are the multiplication of agriculturally productive land (by growing

Table 1: Daily weather condition and irrigation applied

Observation Date	Weather condition	Irrigation water (ml)						
		Layer 1		Layer 2		Layer 3		Horizonal layer
		Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2	
27/12/2017	Sunny							
28/12/2017	Sunny	20	12	20	12	25	25	30
29/12/2017	Sunny	/						
30/12/2017	Little cloudy	20	12	20	12	25	25	30
31/12/2017	Haze							
01/01/2018	Scattered Clouds	15	10	15	10	20	20	25
02/01/2018	Drizzle, overcast							
03/01/2018	Overcast							
04/01/2018	Sunny	20	12	20	12	25	25	30
05/01/2018	Sunny	/						
06/01/2018	Partly Sunny	20	12	20	12	25	25	30
07/01/2018	Fog	15	10	15	10	20	20	30
11/01/2018	Sunny	20	12	20	12	25	25	30
12/01/2018	Hazy Sun	/						
13/01/2018	Haze							
14/01/2018	Sunny	20	12	20	12	25	25	30
15/01/2018	Partly Sunny	20	12	20	12	25	25	30
16/01/2018	Partly Sunny	20	12	20	12	25	25	30
17/01/2018	Partly Sunny	20	12	20	12	25	25	30
18/01/2018	Partly Sunny	20	12	20	12	25	25	30
19/01/2018	Sunny	20	12	20	12	25	25	30
24/01/2018	Partly Sunny	20	12	20	12	25	25	30
25/01/2018	Overcast							
26/01/2018	Overcast							
27/01/2018	Sunny							

in vertically mounted stacks), which reduces the dependency on land use, thus allowing in regrowth of forest. Moreover, due to less use of equipment CO_2 emission get reduced, thus protecting our environment. In addition, vertical farming, applied in a holistic approach in conjunction with other technologies, can allow urban areas

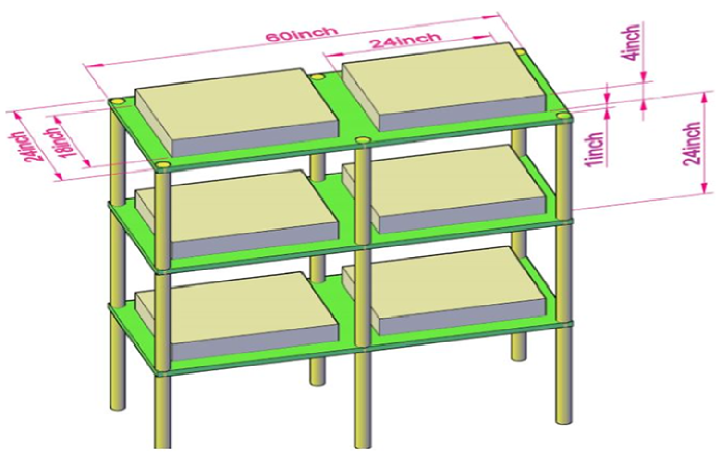

Figure 1: Structural design (three-dimensional) of vertical farm

to absorb the expected influx of more population and yet still remain food sufficient. The technology could provide more employment to the rural populace expected to converge to the cities in the years to come. As per study, red amaranth was not cultivated on vertical farm, using soil as growing medium.

Therefore, the purpose of the study was to construct a Vertical Farm to produce red amaranth and evaluate its sustainability in the roof top.

On the basis of the above proposition the present study was undertaken with the following specific objectives:1. To determine the growth rate of red amaranth in different layers of a vertical farm.2. To compare the yield production of red amaranth in a vertical farm with a horizontal farm.

MATERIALS AND METHODS

Providing plants with their essential nutrients and proper growing conditions in a vertical farming is important for plant health and growth. BARI LALSHAK-1 variety of red amaranth (*Amaranthus oleraceus)* was cultivated in this study. Red amaranth grows well in a variety of soil types but loamy and sandy loam soil is suitable. For better yield cow dung, urea, TSP, and Gypsum was used as a growing medium for this experiment. This chapter deals with the methods and techniques for growing red amaranth on vertical farming system.

Site Selection: Successful growing of crop one of the basic elements is site selection. The ideal location helps to produce crops in the vertical farm where structure get maximum exposure to the sun. Although red amaranth can be grown throughout the years, winter is best. In this study, the location was selected for growing red amaranth on the vertical farm at the roof top of Agricultural Engineering and Technology building.

Raw materials: Raw materials (Bamboo, pin, wire, polythene) were collected for vertical farm construction. Sandy loam soil was collected from the field of Sylhet Agricultural University. Cow dung was collected from the “Dairy Farm” which is beside the Sylhet Agricultural University, Sylhet. Urea, TSP and Gypsum fertilizers and other construction materials were collected from local market named “Noya bazar”, which is situated near the Sylhet Agricultural University.

Design of structure: Vertical structure was designed by using AutoCAD before the experimentation. A three-dimensional view was designed as shown in Figure 1. The designed vertical farm was divided into three layers and each layer was divided into two different plots.

Construction of vertical farm: The structure was constructed by using bamboo. Dimension of the whole structure was Length X Width (5' x 2'). Three-layer was made by cutting bamboo in thin pieces and then the pins were used to adjoin. Six bamboos of 6 feet long were used as the column. Then the layer was made and tightened with the wire. The gap between two layers was kept 2 feet. Polythene sheet was used above each layer so that soil and water could not have washed away. The structure was placed in a suitable position to ensure maximum exposure to sunlight as shown in figure 2.

Calculation of cultivated area: The cultivated area was calculated for the vertical farm by using the following mathematical expression:

Cultivated area: $\frac{24*18}{12*12} * 6 = 18\text{ft}^2$

Figure 2: Different views of vertical structure

Figure 3: Measurement of weight, height of plant and depth of root

Where,
Length=24”, Width= 18”, No. of plot= 6

Amount of soil: $\frac{24*18*4}{12*12*12} * 6 = 6 \text{ ft}^3$

Where,
Length=24”, Width= 18”, Depth=4”, No. of plot=6

Soil preparation: Soil was prepared in the following steps:

1. Soil was collected and finely prepared using hammer then mixed properly with cow dung (3kg).
2. The soil was kept on the floor by covering polythene for three days.
3. After three days Urea (30gm), TSP (20gm), and Gypsum (5gm) fertilizers were mixed with the soil.
4. Then the soil was placed on the two small plots in each vertical layer.
5. All weight was measured using analytical balance.

Seeding: 30 grams seed was collected and divided equally into six portions. The weighted seed was broadcasted carefully in each plot. Seed were covered by top soil to create favourable conditions for proper germination.

Observation of weather condition and irrigation schedule: Irrigation water was measured using a beaker and applied according to the requirements. The applied irrigation water was recorded properly in the research notebook during the study period are given in Table 1. Carefully weather condition and moisture content was observed in everyday until harvesting of red amaranth.

Collection of crop data: Ten red amaranth plants were picked from each plot and the average number of leaves for ten plants of each plot was taken. The weight of plants was measured in an electrical precision balance. To maintain the accuracy of measurement for each plot was performed three times and average weight was taken for each observation. Crop length was measured using a centimetre’s stainless scale and average length was recorded. The same procedure was taken to measure the length of the main root of the plants as shown in Figure 3.

Data Analysis: Statistical analysis was done using "Statistix 10" software for the yield production of red amaranth in different layers of the vertical farm and horizontal layers. Yield production was analysed in terms of height, weight of crop and number of leaves.

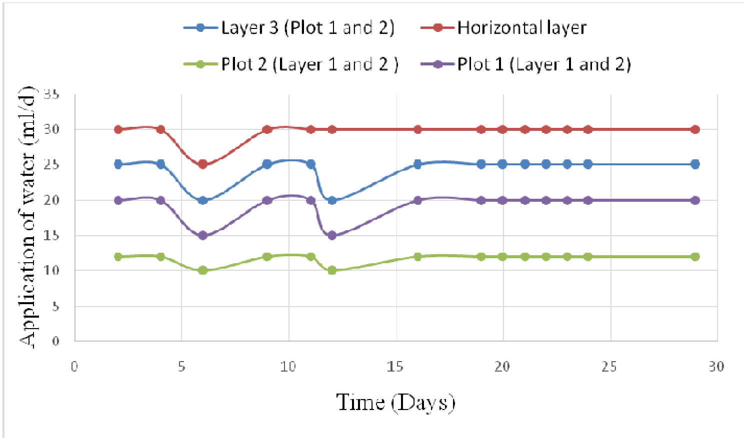

Figure 4: Irrigation water applied in different layers

Table 2: Different measured parameters of red amaranth plant

Crop Yield						
Measurement parameter	Layer 1		Layer 2		Layer 3	
	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
Number of leaf per crop	7-8	5-6	7-8	5-6	7-9	7-9
Height of crop in cm	10-13	9-12	10-13	8-12	13-15	13-15
Weight of crop in gram	1-1.5	1.5-2	1-1.5	1.5-2	2-3.5	2-3.5
Root zone depth in cm	2	2-3	2	2-3	4	4

RESULTS AND DISCUSSION

Depth of irrigation water: Water is the vital element for every living thing. The graph at Figure 4 illustrates that highest amount of water 30 ml was applied in the horizontal farm. Because of, in the horizontal farm water was lost not only by evapotranspiration but also seepage and percolation losses. The result shows that less water was consumed in plot 2 of layer 1 and 2 due to less exposure of sunlight. It is clearly seen that a considerable amount of water was saved in the vertical farm, by providing polythene which was reduced percolation losses. Maximum 30 ml per day of water was applied in horizontal layer during the study period. Whereas, 20 ml per day of water was applied in vertical farm during study period.

In layer 3 plot 1 and 2 was produced highest yield with respect to number of leaves (9 Nos.), crop height (15cm) and weight (3.5 gm), it might be the same environmental condition was experienced, especially the exposure to the sunlight (Table 2). In this study observed that Plot 2 of layer 1 and 2 yield was lowest, whereas plot 1 of layer 1 and 2 yield was medium. This difference in yield production occurred due to the discrepancy in the duration of exposure to the sunlight.

Growth rate of red amaranth: Figure 5 presents that the maximum height of the red amaranth was found 15 cm of Layer 3 in both plots after 30 days. It is clearly indicating that the growth rate was same for plot 1 and 2 of Layer 3 which was occurred due to same environmental conditions. Although the result reveals that the yield of plot 1 of Layer 1 and 2was same, whereas the yield of plot 2 of Layer 1 and 2 was minimum. The variation of results was happened might be due to variation of the sunlight, for the presence of building wall was on the east side which was blocked some of the sunlight in the early morning.

Comparison of red amaranth yields: To understand the sustainability of vertical farming system with respect to horizontal farming should be investigated by comparing yield production with respect to number of leaves, height, weight and root zone depth of red amaranth. The vertical

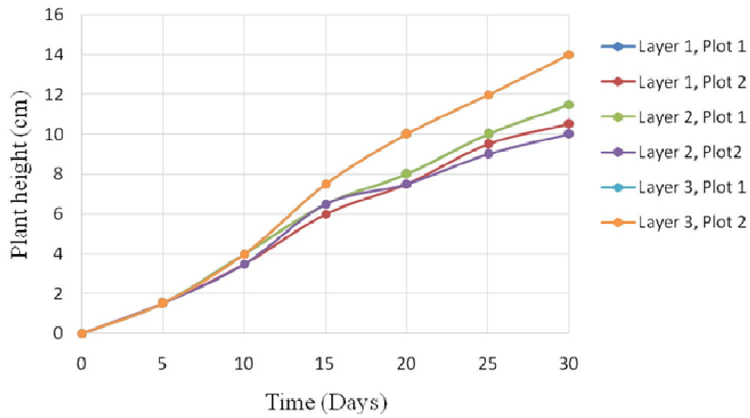

Figure 5: Growth rate of red amaranth in different layers

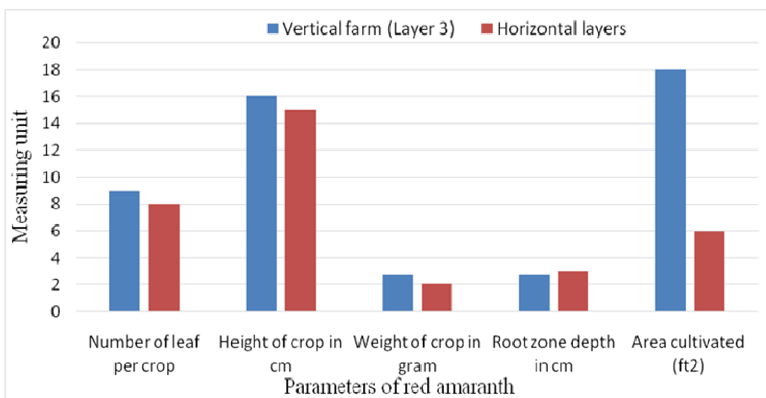

Figure 6: Comparison of yield production between vertical and horizontal farm

farm area was three times greater than the horizontal farm as shown in figure 6. If consider yield of one layer of vertical farm compare with the horizontal layer, it can be seen, vertical farm can grow high-quality red amaranth, providing same growing medium. Moreover, it can be grown extra two layers to cultivate, though the yield production is less on those layers, due to lack of sunlight. So, overall yield production is higher than that of the horizontal layer.

The different growing stages of plants were observed in each layer and plot. Figure 9 shows the plants after 7 days and after 30 days of growth. Most of the plants were grown well as shown in Figure 7.

Statistical analysis: In this study statistical analysis was done by Complete Randomized Design (CRD). Table 3 shows that Treatment 1, 2, 3 and 4 in Layer 1, Layer 2, Layer 3 and horizontal layer respectively. In this study the null hypothesis represents no difference in yield production among 4 layers.

F value 17.57 depicts the result was significant, so the null hypothesis was rejected, that is there was a significant difference in terms plants height among different layers as shown in table 4.

Table 5 depicts that there were 2 groups (A and B) in which the means were not significantly different from one another. Least significant different (LSD) is seen in between treatment 3 and 4, and in between treatment 1 and 2. It means the treatment 3 was the best than all others treatments, whereas treatment 1 was poorest in terms of plants height.

F value 5.7 depicts the result was significant, so the null hypothesis was rejected, that is there was a significant

Figure 7: Pictorial view of red amaranth growth stages in vertical farm

Table 3: Crop data at different layer

Treatment	Replication	Height (cm)	No. of leaf	Wt. of crop (gm)
1	1	12	8	1.5
2	1	13	8	1.5
3	1	15	9	3.5
4	1	15	8	2.2
1	2	13	6	2
2	2	12	6	1.5
3	2	16	9	3.75
4	2	16	10	2.5
1	3	12.5	7	1.4
2	3	12.5	7	2
3	3	15.5	10	3.8
4	3	14	9	2.4

Table 4: Completely Randomized AOV for Height of Crop

Source	Degree of Freedom (DF)	Sum of Square (SS)	Mean Square (MS)	F
Treatment	3	23.0625	7.6875	17.57***
Error	8	3.5	0.4375	
Total	11	26.5625		
Grand Mean	13.875	Coefficient of variation (CV)	4.77	

*** denotes the result was significant at 1% level

Table 6: Completely Randomized AOV for leaves

Source	Degree of Freedom (DF)	Sum of Square (SS)	Mean Square (MS)	F
Treat	3	14.25	4.75	5.7**
Error	8	6.6667	0.83333	
Total	11	20.9167		
Grand Mean	8.0833	Coefficient of variation (CV)	11.29	

** denotes the result was significant at 5% level

Table 7: LSD All-Pairwise Comparisons Test of the leaf by Treatment

Treatment	Mean	Homogeneous Groups
3	**9.3333**	**A**
4	**9**	**A**
1	**7**	**B**
2	**7**	**B**

Table 8: Completely Randomized AOV for Weight

Source	Degree of Freedom (DF)	Sum of Square (SS)	Mean Square (MS)	F
Treat	3	8.27396	2.75799	46.78***
Error	8	0.47167	0.05896	
Total	11	8.74563		
Grand Mean	2.3375	CV	10.39	

*** denotes the result was significant at 1% level

Table 9: LSD All-Pairwise Comparisons Test of Weight by Treatment

Treatment	Mean	Homogeneous Groups
3	3.6833	A
4	2.3667	B
2	1.6667	C
1	1.6333	C

difference in terms of leaves of crop among different layers as shown in table 6.

Table 7 shows that there were 2 groups (A and B) in which the means are not significantly different from one another. Least significant different (LSD) is seen in between treatment 3 and 4, and in between treatment 1 and 2. It can be also seen that treatment 3 is the best whereas treatment 1 is poorest in terms of the number of the leaf of the crop.

F value 46.78 depicts the result was significant, so the null hypothesis was rejected, that is there was a significant difference in terms weight of crop among different layers as shown in table 8.

Table 9 depicts that there are 3 groups (A, B and C) in which the means are not significantly different from one another. Highest weight is seen at treatment 3 which is followed by treatment 4. Whereas, lowest weight is seen in treatment 1.

CONCLUSION

As technology enables new farming opportunities in indoor, food production can be retooled in vertical farm to accommodate high-density urban living and maintain food security despite of a future of decreasing arable land. Therefore, in this paper an attempt has been made to cultivate red amaranth to investigate the growing rate and sustainability of the vertical farm. The novelty of this research is cultivation of red amaranth in the vertical farm. Experimentation showed, though there was significant difference in yield production among different layers, a quality yield can be produced in roof top, using vertical farming system. Most quality yields were grown (number of leaves 9, plant height 15 cm, plant weight 3.5 gm.) in the uppermost layer of the structure. Lowest yield production (number of leaves 7, height of plant 10cm, and weight of plant 1.5gm) was observed in lower layer. The vertical farming technology in agriculture can bring a new option by enabling farming in closer proximity to the city centres. Moreover, it can be grown food in the heart of city with minimal resource consumption and maximum resource efficiency.

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