PERFORMANCE EVALUATION OF VERTICAL FARMING STRUCTURES

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PROJECT REPORT

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DECLARATION

We hereby declare that, this project entitled "**PERFORMANCE EVALUATION OF VERTICAL FARMING STRUCTURES"** is a bonafide record of project work done by us during the course of study, and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this project entitled **“PERFORMANCE EVALUATIONOF VERTICAL FARMING STRUCTURES”** is a record of project work done jointly by Aji E.B. and Faseela O.A. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

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AJI E.B.

FASEELA O.A.

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SYMBOLS ANDABBREVIATIONS

Agric.	Agriculture
C	Carbon
cm	Centimeters
˚C	Degree Celsius
dB	Decibel
Dept.	Department
EU	European Union
eg	Example
et al	And others
fig.	Figure
ft	Feet
°F	Degree Fahrenheit
g	Gram (s)
/m^2	Gram (s) per square meter (s)
GHS	Green House Gas
ha	hectare
hp	hourse power
hrs	Hours
i.e.	That is
inch	inches

int.	international
j.	Journal
K	potassium
KAU	Kerala Agricultural University
KCAET	Kelappaji College of Agricultural Engineering And Technology
KCl	Potssium Chloride
$kg(f)/cm^2$	kilogram force per centimeter square
kg/cm^2	kilogram per centimeter square
kg/ha	kilogram per hectare
kg/m^2	kilogram per meter square
KPa	Kilo pascal
Ltd.	Limited
LDCs	Least Developed Countries
LED	Light Emitting Diode
LWRCE	Land and Water Resources and Conservation Engineering
m	Meter (s)

m^2	Square meter (s)
ml	milli liter
mm	millimeter
N	Nitrogen
No. of	number of
P	Phosphorus
PVC	Poly Vinyl Chloride
sec	Second
ton/acare	Tone(s) per acre(s)
U. S	United States Department of Agriculture
V	Volt
VF	Vertical Farming
VFS	Vertical Farming Structure
VFS1	Vertical Farming Structure One
VFS2	Vertical Farming Structure Two
W	Watts
&	and
°	Degree (s)
/	Per

%	percentage
′	Minute (s)
′′	second

APPENDICES

APPENDIX I

Variation of Air temperature (°C) of VFS1 and VFS2 at 8:00 am during three week period

TIME (week)	1st WEEK	2nd WEEK	3rd WEEK
VFS1	27.9	27.6	27.6
VFS2	27.8	28.2	27.3

APPENDIX II

Variation of Air temperature (°C) of VFS1 and VFS2 at 1:30 pm during three week period

TIME (week)	1st WEEK	2nd WEEK	3rd WEEK
VFS1	32.8	33.7	33.1
VFS2	36.6	34.4	34.5

APPENDIX III

Variation of Air temperature (°C) of VFS1 and VFS2 at 5:00 pm during three week period

TIME (week)	1st WEEK	2nd WEEK	3rd WEEK
VFS1	28.7	29.3	30.8
VFS2	29.4	29.4	30.6

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TIME (week)	1st WEEK	2nd WEEK	3rd WEEK
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VFS2	68.7	58.4	63.3

APPENDIX V

Variation of Relative Humidity (%) of VFS1 and VFS2 at 1:30 pm during three week period

TIME (week)	1st WEEK	2nd WEEK	3rd WEEK
VFS1	55.4	45.2	50.1
VFS2	52.3	39.1	49.9

APPENDIX VI

Variation of Relative Humidity (%) of VFS1 and VFS2 at 5:00 pm during three week period

TIME (week)	1st WEEK	2nd WEEK	3rd WEEK
VFS1	66.5	55.4	61.5
VFS2	61.9	52.6	56.5

APPENDIX VII

Variation of Light intensity (lux) of VFS1 and VFS2 at 8:00 am during three week period

TIME (week)	1st WEEK	2nd WEEK	3rd WEEK
VFS1	6706.9	14898.7	6687.8
VFS2	6727.4	13858.9	7474.4

APPENDIX VIII

Variation of Light intensity (lux) of VFS1 and VFS2 at 1:30 pm during three week period

TIME (week)	1st WEEK	2nd WEEK	3rd WEEK
VFS1	26361.9	30487.2	27536.4
VFS2	26626.2	25722.8	22599.9

APPENDIX IX

Variation of Light intensity (lux) of VFS1 and VFS2 at 5:00 pm during three week period

TIME (week)	1st WEEK	2nd WEEK	3rd WEEK
VFS1	5454.2	6062.6	5119.9
VFS2	5688.5	4144	4127.1

APPENDIX X

Variation of Moisture Content in Rooting Media at a depth of 6 cm during three week period

TREATMENTS	WEEK 1	WEEK 2	WEEK 3
T1 VFS1	24.4	24.3	22.9
T1 VFS2	25.1	24.5	23.3
T2 VFS1	23.5	24.2	22.7
T2 VFS2	24.5	24.2	22.9
T3 VFS1	19.7	22.6	19.5
T3 VFS2	20.6	18.2	18.7
T4 VFS1	19.1	21.4	19.1
T4 VFS2	19.6	17.2	16.8

APPENDIX XI

Variation of Plant Height in treatments T1,T2,T3 and T4 of VFS1 and VFS2

Time(week)	Plant height (cm)							
	T1		T2		T3		T4	
	VFS1	VFS2	VFS1	VFS2	VFS1	VFS2	VFS1	VFS2
1st week	11.8	13.2	12.8	15.6	16.5	14.1	15.8	16.8
2nd week	14.8	22.4	17.1	25.4	22.3	25.7	23	29.2
3rd week	24.8	34.4	27.5	36.4	32.9	37.5	34	42

APPENDIX XII

Variation of Plant Girth in treatments T1, T2,T3 and T4 of VFS1 and VFS2

Time(week)	Plant Girth (mm)							
	T1		T2		T3		T4	
	VFS1	VFS2	VFS1	VFS2	VFS1	VFS2	VFS1	VFS2
1st week	16	15	15	17	21	19	20	20
2nd week	16	26	22	29	30	27	26	27
3rd week	17	29	23	26	31	29	29	31

APPENDIX XIII

Variation of Number of Leaves of Amaranthus in treatments T1, T2,T3 and T4 of VFS1 and VFS2

Time(week)	Number of leaves							
	T1		T2		T3		T4	
	VFS1	VFS2	VFS1	VFS2	VFS1	VFS2	VFS1	VFS2
1^{st} week	6	8	6	9	7	10	9	10
2^{nd} week	9	13	9	15	12	13	15	16
3^{rd} week	18	24	29	27	24	28	27	30

APPENDIX XIV

Yield of Amaranthus from VFS1 and VFS2

TREATMENTS	Weight (kg/ha)	
	VFS1	VFS2
T1	1145	14285.7
T2	833.3	12028
T3	3333.3	11556.6
T4	3333.3	14386.7

CHAPTER I

INTRODUCTION

Agriculture is the human enterprise by which natural ecosystems are transformed into ones devoted to the production of food, fiber. Given the current size of the human population, agriculture is essential. Without the enhanced production of edible biomass that characterizes agricultural systems, there would simply not be enough to eat. The land, water, and energy resources required to support this level of food production are vast.

Most challenging task for agricultural sciences today is to ensure for continuous and enough supply of food to growing human civilization. Urban centers throughout the world have experienced substantial increase in population; this growth is accompanied with change in food habits and rising concerns for food quality. By the year 2050, nearly 80% of the earth population will reside in the urban centers. Applying the most conservation estimates to current demographic trends, the human population will increase by about 3 billion people during the interim. An estimated 10^9 hectares of new land will be needed to grow enough food to feed them, if traditional farming practices continue as they are practiced today. (Kukku Joseph Jose, 2013)

Land is scarce in India, even though the country has a land area of about 328 million hectares which is the seventh largest land area among the countries of the world. India is burdened with a population of 1210 million as per the 2011 census, which grew from 345 million in 1947 with a growth rate of 1.76 in the last decade. Population density has increased from 117 per sq.km in 1951 to 368 in 2011. The estimated population of India in 2016 is around 1.34 billion as per the current records. The land is not increasing corresponding to the population requirement. From this we can conclude that there is no enough space to produce grains for feeding the coming population. (Sureshkumar, 2012)

With the increase in worldwide population growth, the demand for both more food and more land to grow food is ever increasing. But some entrepreneurs and farmers are beginning to look up, not out, for space to grow more food. One solution to our need for more space might be found in the abandoned warehouses in our cities, new buildings built on environmentally damaged lands, and even in used shipping containers from ocean transports. This solution, called vertical farming, involves growing crops in controlled indoor environments with precise light, nutrients, and temperature. In vertical farming, growing plants are stacked in layers that may reach several stories tall.

1.1 Vertical farming

Vertical farming as a component of urban agriculture is the practice of cultivating food within a skyscraper greenhouse or on vertically inclined surfaces. Vertical farming is a greenhouse-based method of agriculture, where commercially viable crops would be cultivated and grown inside multi-storey buildings that will mimic the ecological system. A rapidly growing global population and increasingly limited resources are making the technique of vertical farm more attractive than ever. Global demand for food is growing yearly. The vertical farm has the potential to solve the problem. The vertical gardens was existed in the form of hanging gardens in pre-Columbian Mexico and India, and in some of the Spanish homes of 16th - 17th century in Mexico.(Goode and Patrick , 1986.)

Vertical farming concept is an ongoing project that has grown over the last decade. It was started by Dr.DicksonDespomier, Prof. of Environmental Health Science and Microbiology at Columbia university considered as the father of vertical farming concept.

In the U.S. alone, studies show that population increases by as much as 5,000 per day while the land correspondingly decreases by 15,000 acres. Based on agricultural reports, about 24 billion tons of topsoil are lost yearly due to farming methods. Over irrigation on the other hand has caused the depletion of natural resources of ground water that supplies fresh water to wells and springs. Too much water is being drawn off the ground causing the water table to go down at an uncomfortable level. Other sources of water cannot be relied upon because it has been contaminated by agricultural run-off that contains pesticides. Hence, the concept of vertical farming being used by some small scale industries for the past 15 years, is now gaining technological attention. This method of vertical farming will include the production of freshwater fishes, crustaceans, and mollusks, like tilapia, striped bass, trout, shrimps, crayfish and mussels. The success of vertical farming as the answer to the imminent problem of food shortage is also foreseen as a means of rehabilitating vast agricultural lands that were systematically eroded by aggressive commercial farming for the past 20 to 30 years.

Water scarcity has a huge impact on food production. Without water people do not have a means of watering their crops and, therefore, to provide food for the fast growing population. According to the International Water Management Institute , agriculture, which accounts for about 70% of global water withdrawals, constantly competing with domestic, industrial and environmental uses for a scarce water supply.

In India, scientists are working on a module to grow vegetables and fruits in multistoried structures. With farm land becoming scarce, ICAR experts are working in the concepts of 'vertical farming' in soilless conditions, in which food crop can be grown even on multistoried buildings in metros like New Delhi, Mumbai, Kolkata and Chennai without using soil or pesticides.(Dutta, 2013)

1.2 ADVANTAGES

1.2.1 Continuous Crop Production

Vertical farming technology can ensure crop production year-round in non-tropical regions and the production is much more efficient than land-based farming. According to Despommier, a single indoor acre of a vertical farm may produce yield equivalent to more than 30 acres of farmland, when the number of crops produced per season is taken into account.

1.2.2 Elimination of Herbicides and Pesticides

The controlled growing conditions in a vertical farm allow a reduction or total abandonment of the use of chemical pesticides

1.2.3 Protection from Weather-Related Variations in Crop Production

Because crops in a vertical farm are grown under a controlled environment, they are safe from extreme weather occurrences such as droughts, hail, and floods.

1.2.4 Water Conservation and Recycling

Hydroponic growing techniques used in vertical farms use about 70% less water than normal agriculture. Aeroponic growing techniques saves 95% of water used by conventional land based farms.

1.2.5 Climate Friendly

Growing crops in indoors reduces or eliminates the use of tractors and other large farm equipment commonly used on outdoor farms, thus reducing the burning of fossil fuel.

According to Despommier, deploying of vertical farms on a large scale could result in a significant reduction in air pollution and in CO2 emissions. Furthermore, carbon emissions might be reduced because crops from a vertical farm are usually shipped just a few blocks from the production facility, instead of being trucked or shipped hundreds or thousands of miles from a conventional farm to a market.

1.2.6 Poverty/Destitution and Culture

Food insecurity is one of the primary factors leading to absolute poverty. Being able to construct 'farm land' in secure areas will help to alleviate the pressures causing crisis among neighbours fighting for resources (mainly water and space). It also allows continued growth of culturally significant food items without sacrificing sustainability or basic needs, which can be significant to the recovery of a society from poverty.

1.2.7 Energy production

Vertical farms could exploit methane digesters to generate a small portion of its own electrical needs. Methane digesters could be built on site to transform the organic waste generated at the farm into biogas which is generally composed of 65% methane along with other gases. This biogas could then be burned to generate electricity for the greenhouse.

1.2.8 Sustainable urban growth

Vertical farming, applied with a holistic approach in combination with other technologies, will help urban areas to absorb the expected rise in population and yet still remain food sufficient. However, traditional farming will continue because many crops are not suited to indoor farming.

1.2.9 Preparation for the future

To meet the demands of the growing population requires additional hectares of land. But no additional lands are available. Vertical farms, if designed properly, may eliminate the need to create additional farmlands and help to create a cleaner environment.

1.3 DISADVANTAGES

1.3.1 Land and Building Costs

Urban locations for vertical farms can be quite expensive.

1.3.2 Energy Use

Although transportation costs may be significantly less than in conventional agriculture, the energy consumption for artificial lighting and climate control in a vertical farm can add operations costs significantly.

1.3.3 Controversy over USDA Organic Certification

It is unclear if or when there will be agreement on whether crops produced in a vertical farm can be certified organic. Many agricultural specialists feel that a certified organic crop involves an entire soil ecosystem and natural system, not just the lack of pesticides and herbicides.

1.3.4 Limited Number of Crop Species

The current model for crops grown in vertical farms focuses on high-value, rapid-growing, small-footprint, and quick-turnover crops, such as lettuce, basil, and other salad items. Slower-growing vegetables, as well as grains, aren't as profitable in a commercial vertical farming system.

1.3.5 Pollination Needs

Crops requiring insect pollination are at a disadvantage in a vertical farm, since insects are usually excluded from the growing environment. Plants requiring pollination may need to be pollinated by hand, requiring staff, time and labour. (Jeff Birkky, 2016.)

In view of all the above facts this study has been undertaken to evaluate with the following specific objectives:

1. To compare the performance of existing VFS by orienting in North-South direction
2. To optimize the level of irrigation inside VFS in soilless media and soil media

CHAPTER II

REVIEW OF LITERATURE

Our modern way of life is centered on mega-cities. This is likely to continue, as the percentage of the global population living in, or very close to, major cities rises past 80%. It would make sense, then, that any new innovative farming system should begin here, as it will benefit the greatest number of people, while offering low-cost solutions for abundance within a small space.

Urban agriculture offers a new frontier for land use planners and landscape designers to become involved in the development and transformation of cities to support community farms, allotment gardens, rooftop gardening, edible landscaping, urban forests, and other productive features of the urban environment. Despite the growing interest in urban agriculture, urban planners and landscape designers are often ill-equipped to integrate food-systems thinking into future plans for cities.

The Vertical Farming is the advanced level of agriculture technology where this has to be practiced when there is unavailable of land and other requirements for the perfect structure of farming mode, this is the new way or approach in the advanced level and which is deals with the methodology, harvesting technique, water management and crop cultivation & yielding process.

2.1 Constraints in Improving Agricultural Production

Dayo Phillip (2009) studied on constraints in increasing agricultural productivity in Nigeria. These constraints include those arising from agricultural policies formulated over time. Some constraints, such as poor and untimely release of funds and high offshore costs of equipment, limit the implementation of the presidential initiatives. Others, such as aging and inefficient processing equipment and high on-farm costs of agrochemicals, limit the effective functioning of the value chains (production, processing, and marketing) for key agricultural commodities.

The study conducted by Turner and Allison H. (2009) concluded that contaminated soil posses challenges for agricultural uses, as urban farmers, gardeners, and bystanders (particularly children) can absorb contaminants into their bodies via skin contact with, ingestion of, or inhalation of contaminated soil or plants.

2.2 Urban agriculture

Chaney *et al. (*1984) conducted a study on the potential for heavy metal exposure from urban gardens and soils. Eating vegetables grown in contaminated soils could cause health problems because the plants generally absorb heavy metals in their edible tissues. They also revealed that rainwater is the best source of water for watering plants; it reduces the pressure exerted on the municipal water network. The temperature of rainwater is naturally warm and will not shock the plants, contrary to cold water from the waterworks system. In addition, this water does not contain chlorine, which inhibits plant growth.

Hynes and Patricia (1996) concluded that urban agriculture can contribute significantly to the development of social connections, capacity building, and community empowerment in urban neighborhoods, most commonly through community gardening.

Brown and Jameton (2000) conducted a study on the public health implications of urban agriculture and concluded that the cities can contribute to positive health outcomes directly.

Kaufman and Bailkey (2000) reported that the urban agriculture can contribute to environmental management and the productive reuse of contaminated land, including brown fields. As a result of increased plant foliage, urban agriculture can reduce storm water runoff and air pollution, and can increase urban biodiversity and species preservation.

Hansen and Donohoe (2003) conducted a study on health issues of migrant and seasonal farm workers. The study indicated that industrial agriculture has till date used agricultural machinery, advanced farming practices and genetic technology to increase yield. However, agriculture still largely depends on season, especially in case of fruit and vegetable crops. Socio-economically this renders the farming population under or unemployed for a greater part of the year. While in industrialized nations, higher food prices, greater affordability and government subsidies ease this problem to some extent, in developing countries, where subsistence agriculture is the norm, this translates to poverty and vulnerability.

Bellows *et al.* (2004) conducted a study on health benefits of urban agriculture. They concluded that urban agriculture also provides opportunities for public health programming to improve nutrition knowledge, attitudes, and dietary intake.

Dubbeling and Merzthal (2006) reported that urban agriculture presents many economic opportunities. It can decrease public land-maintenance costs, increase local employment opportunities and income generation, and capitalize on underused resources (e.g., rooftops, roadsides, utility rights-of-way, vacant property). Urban agriculture can also increase property values and produce multiplier effects through the attraction of new food-related businesses, including processing facilities, restaurants, community kitchens, farmers markets, transportation, and distribution equipment.

2.3 Vertical Farming

Doernach (1979) found that building protection is primarily by vertical gardens by reducing temperature fluctuations of the building envelope. Decreased temperature fluctuations reduce the expansion and contraction of building materials and extend the building’s lifespan.

Minke (1982) found that without greening, flat roofs were 50% more susceptible to damage after 5 years than slightly sloped roofs (e.g., 5% slopes). This was because water tends to pool instead of running off. If the drainage layer is not sufficient or if drainage routes become blocked, green roofs can cause leak due to continuous contact with water or wet soil. With insufficient drainage, the plants will also be susceptible to the impact of wide degrees of variability in the moisture content of the soil. For example, with too much water, the soil can go sour and the plants can drown or rot.

Goode and Patrick (1986) studied about vertical gardens and found that vertical gardens, in the form of hanging gardens was existed in pre-Columbian Mexico and India, and in some of the Spanish homes of 16th - 17th century in Mexico.

Mitchell (1994) conducted a study on bio regenerative life-support systems. The study found that an estimated 28 m^2 area of intensively farmed indoor space is enough to produce food to support a single individual in an extra-terrestrial environment like a space station or space colony supplying with about 3000 Kcal of energy per day.

In 2001, Dickson Despommier proposed a concept to reduce agriculture's ecological footprint by using vertical farming which built agriculture into the city and expanded it in vertical direction. He reported that the vertical farming concept in Thailand can be conducted with greater effectiveness because of the warm climate when compared to planting in places with a cold climate since there is no need to grow vegetables in a closed environment, which requires climate control.

Yamada (2008) found that green walls in cooling buildings and combating the heat island effect and greatly reduce this effect by absorbing a lot of the heat through the evaporation process.

Walsh, B (2008) reported that it will cost $20 million to $30 million for a prototype, but hundreds of millions to build a 30-story farm. He concluded that with high construction and energy costs, vertically raised food will most likely be more expensive than traditional crops and thus not be able to compete in today’s current market.

Despommier (2010) reported that the VF buildings would have to act as separate standalone. Vertical farms devoted entirely to the purpose of water purification. Instead, biomass produced in these buildings could be used in biofuel production adding an additional cost benefit to the solution. Resulting purified water would be drinking quality and could be used as irrigation water in food-producing vertical farms or simply be reused as drinking water.

Justin White (2010) found that farming in the sky scrapers can withstand the population increases. With all of the money and fuel we spend transporting goods to and from halfway across the country, we could be investing that money into the future of farming. Our crops are constantly being wiped out by floods and fires caused by climate change. The cost of food is consistently increasing due to the beginning lack of fossil fuels. All of these problems can be solved by vertical farming.

Chirantan Banerjee (2013) indicated that among the cultivated crops tomatoes, potatoes and pepper were gave higher yield (155tons/ha, 150 tons/ha, 133 tons/ha respectively) under VF than field yield (45 tons/ha, 28 tons/ha, 30 tons/ha respectively).

Balachandar (2014) reported that although some initial costs of spending such a source of money for building these vertical farms, the best way to overcome land depletion and save agriculture. Hence, he concluded that Vertical Farms are the best choice for agricuture's future.

2.4 Change in climatic parameters

Givoni (1976) cited that the need to re-apply finish surface materials or cladding, the loss of space resulting from thicker walls and the interruption of usage during construction can all be avoided through the use of vertical gardens. In fact, insulation applied to the exterior of buildings is much more effective than interior insulation, especially during the summer months.

Minke and Witter (1982) reported substrate depth of 20-40 cm can hold 10 – 15 cm of water, translating into runoff levels that were 25% below normal. A grass covered roof with a 200-400mm (8-16in.) layer of substrate can hold between 100-150mm (4-6in.) of water.

Hoffman (1995) indicated in his study that micro climates are site-specific; for example, a rooftop will often have a different microclimate from the grade surrounding the building. Microclimate is directly influenced by a variety of elements on and around the site - land contour, vegetation, water, soil conditions, and buildings - which affect the site's sunniness, warmth or coolness, humidity, wind, snowdrift and runoff patterns and degree of wind chill. By manipulating these site elements, the microclimate of a site can be substantially changed.

Christian and Petrie (1996) experimented that a vegetated roof of 0.46-0.76m (1.5-2.5ft.) of soil reduced the peak sensible cooling needs of a building by about 25%. In addition, the green roof did not have a cooling penalty like commercial buildings with high roof insulation levels.

Wilmers (1988) indicated that in Germany, the vertical garden surface temperature was 10°C cooler than a bare wall when observed at 1:30 PM in September.

Banse*et al.* (2008) reported that global climate change presents an opportunity for Vertical Farming to get greater social and political acceptance. In addition to this there is an increasing controversy regarding the use of arable land for bio-fuels and the later contributing towards rising of food prices. Vertical Farming can relieve high yielding land, now used for fruit and vegetable cultivation.

The study conducted by Hakkim*et al.*(2016) concluded that direct sunlight exposure is not at all necessary for plants as the photosynthesis and plant growth depends only on the PAR range. Providing PAR in the form of artificial light with sufficient luminance can support plant growth. Analysis of the results obtained revealed that grow light based vertical farming can be recommended for indoor precision farming in urban areas as a substitute to the conventional farming practice on limited land area.

2.5Rooting media used in vertical farming structures

Minke and Witter (1982) found in Ontario, Canada a typical residential roof is designed for a load of approximately 30-40 lbs per square foot (146-195 kg per square meter), which does not include snow loading. If soil is used as the growing medium, the depth for planting is limited to less than 3 inch (7.6 cm). An extensive green roof is much lighter than an intensive green roof, with the lightest grass roof weighing as little as 11.2 lbs. (55 kg/m 2) including 2.36" (6 cm) of substrate.

Thompson(1998) reported that the growing medium in green walls, typically made up of a mineral-based mix of sand, gravel, crushed brick, lexica, peat, organic matter and some soil, varies in depth between 5-15 cm, a weight increase of 72.6-169.4 kg per m2. Due to the shallowness of the soil and the extreme desert-like microclimate on many roofs, plants must be low and hardy, typically alpine, dryad or indigenous. Plants are watered and fertilized only until they are established and after the first year, maintenance consists of two or three visits a year for weeding of invasive tree and shrub species, mowing, and safety and membrane inspections.

Ellis (2012) showed that the soilless culture has the potential of saving incredible amounts of water compared to current outdoor agricultural techniques. Experience has shown that it can use as little as a 1/20 of the amount of water as regular to produce the same amount of food. The hydroponics use 70% less water than current agricultural practice and geoponics use 70% less water than hydroponics.

Anjithakrishna*et al.*(2014) suggested that VFS can be recommended more precisely for flat balconies in urban areas and as a substitute to the conventional farming practice on limited land area and cocopeat and vermicompost (3:1) ratio is the best rooting media for growing crops in VFS.

2.6Vermicompost

Bhadauria and Ramakrishnan (1996) conducted an experiment on role of earthworms in nitrogen cycle during the cropping phase of shifting agriculture (jhum) in North East India and reported that during the fallow period intervening between two crops at the same site in 5- to15-year jhum system, earthworms participated in N cycle through cast-ejection, mucus production and dead tissue decomposition. The total soil N made available for plant uptake was higher than the total input of N to the soil through the addition of slashed vegetation, inorganic and organic manure, recycled crop residues and weeds.

Evans *et al.* (1996) conducted a study on the source variation in physical and chemical properties of coconut coir dust. The result showed that cocopeat has good physical properties, high total pore space, high water content, low shrinkage, low bulk density and slow bio-degradation.

Jadhav*et al.* (1997) studied the influence of the conjunctive use of FYM, vermicompost and urea on growth and nutrient uptake in rice. The results showed that the uptake of N, phosphorus (P), potassium (K) and magnesium (Mg) by paddy (Oryzasativa) plant was highest when fertilizer was applied in combination with vermicompost.

2.7Drip irrigation system

Bevacqu (2000) conducted a study about the drip irrigation for the row crops. Drip irrigation offers the advantages of improved yields, reduced water use, and the opportunity to distribute agricultural chemicals through the irrigation system. The conversion from furrow to drip irrigation required many changes in production practices. Some of the critical changes are in management of soluble salts, crop rotations, minimum tillage, soil borne pathogens, and fertilizers and soil amendments. The study concluded that drip irrigation produced a 12% greater net operating profit than furrow irrigation.

Thabet M (2013) studied the feasibility of drip irrigation system and determined its impact on water use efficiency and production of pepper (Capsicum annuum. L) which is largely cropped plant of southern Tunisia arid part. In order to conserve precious water resources and maximize crop performance, Tunisian farmers are incited to use drip irrigation method for a subsidy which can reach 60 % of irrigation materials cost.

Zhigang Liu *et al.* (2014) concluded that in different media, the wetting body is shaped like a rotating projectile, whose maximum horizontal infiltration radius occurs at 3–6 cm below the medium surface. Under drip irrigation of the same volume, the volume of the medium wetting body declines while the horizontal and vertical migration rates of the medium wetting front both rise with increasing irrigation flow; additionally, there are declines in medium water content, and water content increment at the same position. Under drip irrigation of the same duration, increasing irrigation flow leads to increases in the volume of the medium wetting body, horizontal and vertical migration rates of the medium wetting front, surface medium water content, and the medium wetting range.

KaijingYanga*et al.* (2016) conducted an experiment to investigate the effects of the proportion of wetted soil (P)and nitrogen fertilizer (N) on potato yield, crop evapotranspiration (ETc), water use efficiency (WUE), and quality under drip irrigation with plastic mulch. The results suggested that potato could be cultivated with a moderate P (40–50%) and an intermediate rate of applied N (135–150 kg N ha−1) under drip irrigation with mulch, achieving acceptable yields and quality while saving irrigation water and conserving N fertilizer.

Vidhya*et al.*(2015) analysed that the plants at the right side of the fabricated VFS had higher growth and yield than any other sides of fabricated VFS and existing VFS for the orientation in the east-west direction. The study suggested that newly fabricated VFS can be recommended more precisely as a substitute to the conventional farming practice on limited problematic land area.

HadiJaafar*et al*. (2016) conducted a research to investigate the effect of different irrigation regimes and nitrogen doses on the morphometric characteristics (shoot height and weight), crop yield, and water productivity of Marjoranasyriaca. The results showed that Marjoranasyriaca adapted best to the higher irrigation regimes, with fresh weight and dry leaf weight higher by 185% and 165% respectively than the lowest irrigation treatment. Although applying medium doses of nitrogen improved yield at higher irrigation regimes, it did not affect the harvest index or crop water productivity.

CHAPTER III

MATERIALS AND METHODS

This chapter describes the materials used and the methods employed for the project under the title "Performance Evaluation of Vertical Farming Structures" conducted in Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, Kerala.

3.1Location of study

The experiment was conducted in KCAET, Tavanur, in Malappuram district, Kerala. The place is situated at 10˚ 52' 30" North latitude and 76˚ East longitude. The total area of KCAET is 40.99 ha, out of which total cropped area are 29.65 ha. Agro climatically, the area falls within the border line of Northern zone and Central Zone of Kerala. Major part of the rainfall in this region is obtained from South West monsoon. The area is having a relative humidity of about 80%. The mean maximum temperature of the area is about 35˚C and mean minimum temperature of the area is about 22˚C. The experimental study was conducted during 29th October to 18th November 2016.

3.2 Installation of Vertical farming system

The site in the northern side of KCAET campus nearer to the staff quarters is selected for the installation of vertical farming structures. Both of the vertical farming structures (VFS) were oriented in North-South direction. In Vertical Farming Structure 1 (VFS1), half split PVC pipes of 6" diameter were used for planting. Half split PVC pipes of 2.80 mm wall thickness and 1.2 m length were provided in the middle rows. Half split PVC pipes of 0.5 m length were provided in the side rows. The PVC splits were supported by semicircular rings made of ¾" x ⅛`" MS flat in each rows. The grow bags and PVC splits were filled with soil and soilless media. The soilless media consists of cocopeat and vermicompost in 3:1 ratio which is recommended by the earlier studies that are done in KCAET. The VFS1 is shown in plate 3.1 and the schematic diagram of VFS1 is shown in fig 3.1. Eight numbers of grow bags with 15cm x 30cm size were placed in each platform of Vertical Farming Structure 2 (VFS2). Arrangement of grow bags in the VFS2 are shown in plate 3.2. The fig.3.2 is showing the schematic diagram of vertical farming structure 2.

Plate 3.1.Vertical Farming Structure 1   Plate 3.2.Vertical Farming Structure 2

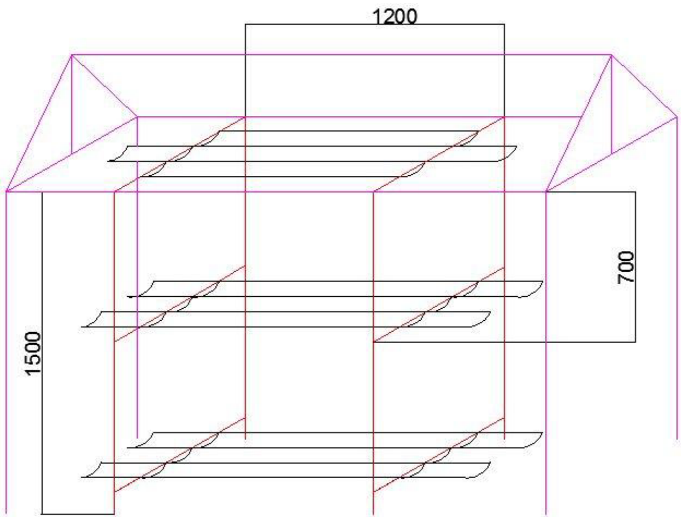

Fig 3.1 Schematic diagram of Vertical Farming Structure 1

(All dimensions are in millimeter)

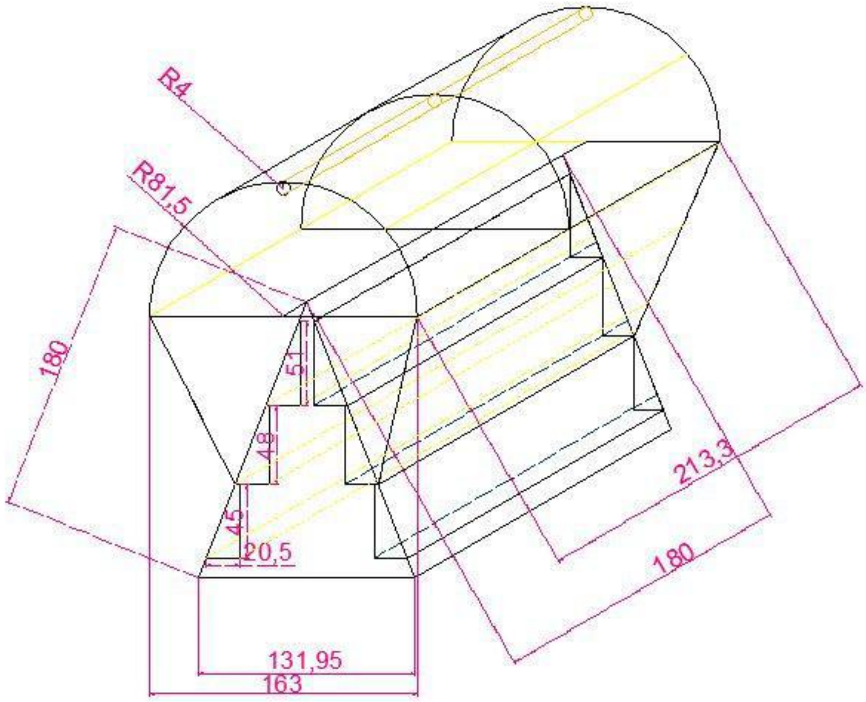

Fig.3.2 Schematic diagram of Vertical Farming Structure 2

(All dimensions are in centimeter)

3.3 Field experiment

3.3.1 Treatment details

Different rooting medium were used in this study. These were filled in half splitted PVC pipes in VFS 1 and in grow bags of VFS 2. Two levels of irrigations were taken for the study. The different treatments used for the study were shown in table 3.1.

Table 3.1. Treatments

Treatment	Component	Level of Irrigation
T1	Cocopeat+ Vermicompost (3:1)	100%
T2	Cocopeat+ Vermicompost (3:1)	70%
T3	Soil	100%
T4	Soil	70%

3.3.2 Layout of experiment

The experimental layout for the VFS 1 and VFS 2 are shown in fig 3.3 and fig 3.4 respectively.

For Tier 1

	T3	
T1	T2	T1
	T4	

For Tier 2

	T2	
T3	T4	T3
	T1	

For Tier 3

	T4	
T1	T2	T1
	T3	

Fig. 3.3 Experimental layout for Vertical Farming Structure 1 (VFS 1)

For Tier 1

T2	T4	T2	T4	T1	T3	T1	T3
T3	T1	T3	T1	T4	T2	T4	T2

For Tier 2

T4	T2	T4	T2	T3	T1	T3	T1
T1	T3	T1	T3	T2	T4	T2	T4

For Tier 3

T2	T4	T2	T4	T1	T3	T1	T3
T3	T1	T3	T1	T4	T2	T4	T2

Fig.3.4. Experimental layout for Vertical Farming Structure 2 (VFS 2)

3.4 Selection of Plants

Selection criteria are based on characteristics such as height of the plant, shape of plant, vitality and resistance to pests and diseases. Amaranth [Amaranthushypochondriacus, A. cruentus (Grain type) and A. tricolor (Vegetable type)] is an herbaceous annual with upright growth habit, cultivated for both its seeds which are used as a grain and its leaves which are used as a vegetable or green. Both leaves and seeds contain protein of an unusually high quality. The grain is milled for flour or popped like popcorn. Amaranth is a valuable nutritious feedstuff with high production ability. The most optimal condition for the crop is humid and well-structured soils but the crop tolerates any soil conditions.CO-1 variety of amaranth is used for the study. Amaranth is thermophilous plant and especially for germination higher temperature of soil is necessary; otherwise older plants tolerate even short-term frost. This crop is resistant to drought thus it does not require as much moisture as other crops. The only exception is germination stage and first couple of weeks in growing season until strong root system is established.

3.5 Planting methods

Amaranthus seedlings of CO-1 variety with 15 days old were used for the trial. The seedlings were transplanted into both. The depth of the rooting media in the half splitted PVCs of VFS1 was about 9.5 cm and grow bags were provided with rooting media mixture of 9 cm depth. Four seedlings were transplanted in each middle row and two seedlings to each of the side rows in the VFS1 with spacing of 30 cm. Two plant was transplanted in each grow bag and placed in the platform of VFS2. Total number of plants in both VFS was 96.

3.6 Irrigation and Fertilizer application

The drip irrigation system was used to irrigate the plants in both vertical farming structures. This was done to reduce the wastage of water during irrigation by supplying adequate quantity of water in the crop root zone. The source of water supply was the main water tank in the campus and the supply is controlled by a ball valve situated nearer to the site. The water was applied to the plants by using main lines and laterals. In VFS1, the laterals are laid along the length which is 1.3m for 3 tiers and the water supply is regulated by valves provided in the laterals. Similarly in VFS2 the laterals are laid for 1.8m along the length of the structure for each platform. At the end of each line an end cap was provided for flushing the line. Optimization of the irrigation requirement is done by adopting 2 levels of irrigation of 100% and 70%. A trial was conducted with an amount of 1000 and 500 ml per day and was applied to each crop through drip in both soil and soil less media. As the depth of the rooting media was only 9cm, this much amount of water caused water logging condition in the root zone and caused 30% and 20% of crop failure. The amount of water applied was then changed and fixed as 250 ml per day per plant. The fertilizer was applied at the rate of 3 to 5 g per plant in a single doze in both VFS. The drip irrigation system installed in VFS1 and VFS2 is shown plate 3.4 and the plate 3.

Plate 3.4 Drip irrigation system in VFS1

Plate 3.5 Drip irrigation system in VFS2

3.7 Observation of climatic parameters

For comparing the performance of crops under two structures, climatic parameters such as temperature, relative humidity, light intensity were observed during morning (8 am), afternoon (1.30pm) and evening (5 pm) hours for a period of three weeks after transplanting(1st week- 29th October 2016 to 4th November 2016, 2nd week- 5th November 2016 to 11th November 2016, 3rd week-12nd November 2016 to 18th November 2016). For comparing the moisture content of rooting media, this was observed once in a day from both structures for a period of three weeks. The air temperature and relative humidity were observed using digital thermometer and the light intensity is measured using lux meter. The daily observations were tabulated and the average values of observations of each week were noted and were used for plotting the graphs.

3.8 Moisture content determination

The irrigation was done in the evening 5pm daily. Moisture content of the rooting media was measured at a depth of 6 cm 24 hours after irrigation. The rooting medium moisture content was observed with digital soil moisture meter.

3.9 Biometric observations

For analyzing the growth pattern of the crops, crops from each tier were selected randomly from each side of the vertical farming structures. Biometric observations such as plant height, girth and number of leaves were taken once in a week. The collected data were tabulated and compared.

3.9.1 Height of the plant

The height of the randomly selected plants was measured from the surface of the rooting media to the tip of the plant in both the VFS.

3.9.2 Girth of the plant

The girth of the plants was measured randomly under each tier of the VFS once in a week. The measurements were taken from the bottom of the stem of each selected plants.

3.9.3 Number of leaves per plant

Number of leaves of randomly selected plants of each tier was counted once in a week for both VFS.

3.9.4 Yield data

Harvesting of the crop was done after attaining maturity.

CHAPTER IV

RESULTS AND DISCUSSION

The study has been undertaken with the objective of comparing the performance of existing vertical farming structures by orienting in North-South direction and to optimize the level of irrigation inside the VFS in soilless and soil media. The study was conducted from October 2016 to November 2016. Amaranthus (CO-1) variety was selected for the experimental trial. The climatological data and biometric observations were taken from the existing VFS. The results of the study are discussed in this chapter.

4.1 Comparison of climatic data

Climatic parameters such as air temperature, relative humidity, and light intensity were observed in the VFS1 and VFS2. The daily observations were noted at 8:00 am, 1:30 pm and 5:00 pm for a period of three weeks from October to November 2016 for the trial with amaranthus. The moisture content of the rooting media was measured once in a day at 5 pm prior to irrigation for three weeks.

4.1.1 Air temperature

The weekly average values for air temperature was calculated for 8:00 am, 1:30 pm and 5:00 pm from the daily data taken. Observations were taken using thermometer. The variations of air temperature at 8:00 am in the VFS1 and VFS2 are shown in fig 4.1. In the first week, temperatures of VFS1 and VFS2 have slight difference but for the second and third week there is notable difference in temperatures between the two VFS compared to first week. The maximum temperature measured in VFS1 was about 27.9ºC and in VFS2 about 28.2ºC. Minimum temperature was noted 27.6ºC at VFS1 and at 27.3ºC VFS2. The variations in temperatures in both structures were mostly in the range of 27 and 28 ˚C. By analyzing the graph, VFS1 shows more temperature during week1 and week3. This is because some of the reflected solar radiation was absorbed by the three tier metal frame during the day time.

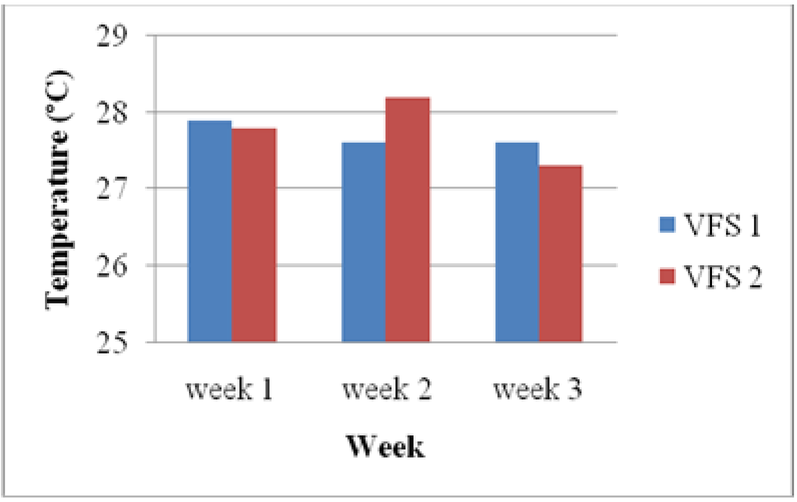

Fig 4.1.Variation of air temperature in VFS1 and VFS2 at 8 am.

The graph shows that there is no notable difference in temperatures in both the structures at 8.00 am during the observation period of three weeks.

A considerable increase in air temperature inside VFS2 was noted compared to VFS1 during the noon hours. Observations of air temperature at 1:30 pm are shown in fig 4.2. The variation was more during the first week than in the second and third week. Maximum temperature noted in VFS1 is 33.7˚C and in VFS2 was 36.6˚C. The maximum temperature is obtained in noon hours and it is because of more solar radiation obtained due to North-South orientation and the chosen site is a shadow free location.

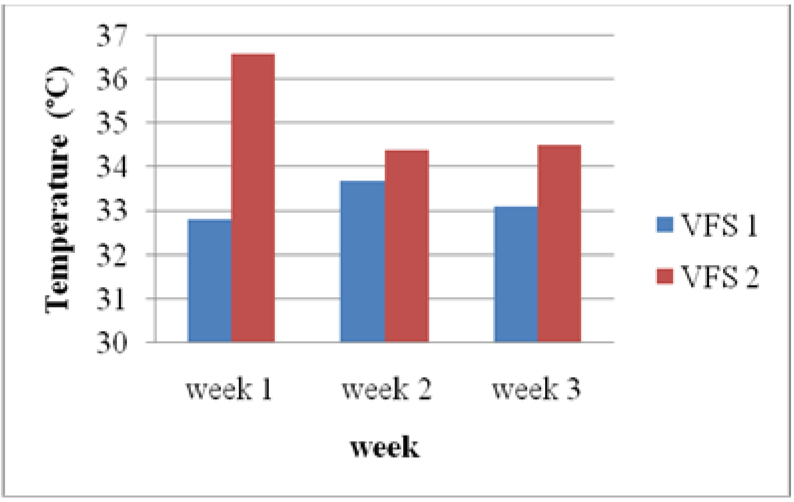

Fig 4.2.Variation of air temperature in VFS1 and VFS2 at 1.30 pm.

Minimum temperatures were 34.4˚C and 32.8˚C respectively. The maximum temperature was observed in VFS2. A variation of 4.6 ˚C was observed in both structures initially, followed by a variation of 0.6 & 1.4 ˚C in subsequent weeks. The graph shows there is considerable difference in temperature in both the structures at 1.30 pm during the observation period of three weeks.

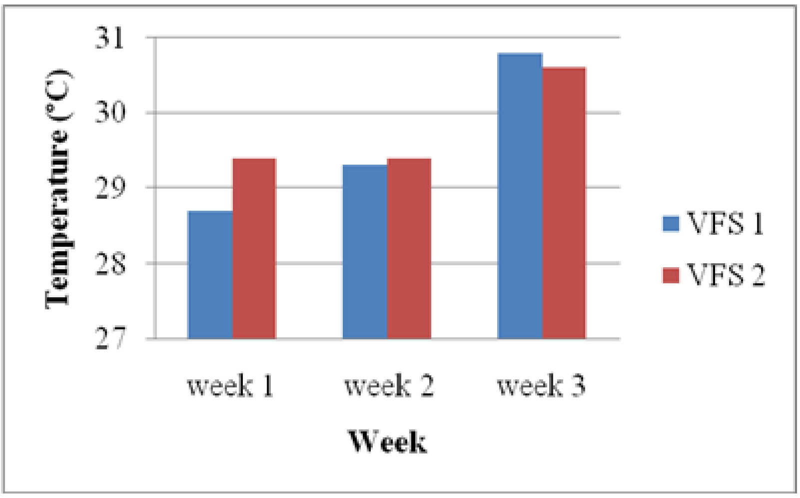

Fig 4.3 Variation of air temperature in VFS1 and VFS2 at 5.00 pm.

The fig 4.3 showing air temperature of VFS1 and VFS2 at 5:00 pm describes that there was a small difference in temperature during the second and third week while there was a reasonable temperature difference in the first week.

Maximum temperature in VFS1 was about 30.8˚C and in VFS2 was 30.6˚C. Minimum temperatures were 28.7°C and 29.4°C respectively. The change in temperature was due to orientation of the structure. A variation of 0.8 ˚C was observed in both structures initially, followed by a variation of 0.2 & 0.4 ˚C in subsequent weeks. The graph shows there is no considerable difference in temperature in both the structures at 5.00 pm during the observation period of three weeks. The maximum temperature in a day was observed at 1:30 pm followed by 5:00 pm in both the VFS. The variations in temperature were also observed more at 1.30 pm compared to 5 pm and 8.30 am. The maximum temperature was observed in VFS 2 in both 1.30 pm and 5.00 pm in every week of observation. There was small variations in air temperatures between both the structures. During the growing stage, the heat of respiration liberated by the crops also has a small role on this observed variation. In third week, both the VFS1 and VFS2 show almost same air temperature. After the full establishment of plants, heat was absorbed by the plants.

4.2 Relative Humidity

The weekly average values for relative humidity was calculated for 8:00 am, 1:30 pm and 5:00 pm respectively from the daily data taken. The values of relative humidity observed at 8 am for the three weeks are shown in fig.4.4. From the graph it is clear that the relative humidity is almost same for both structures in the first week due to the temperature difference is almost same. The highest values of relative humidity were observed in the morning time due to the cooling effects of plants combined with the least air temperature in the morning. The maximum RH measured in the morning in VFS1 is 68.9% and in VFS2 it is 68.7%.

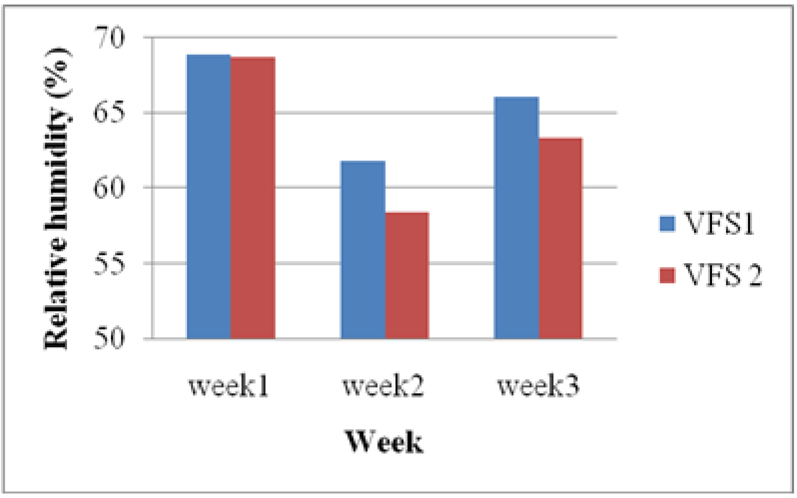

Fig 4.4 Variation of relative humidity in VFS1 and VFS2 at 8:00 am.

There is slight variation in RH in the second week. A variation of 3.7 & 3% in RH was observed in second and third week in both VFS respectively. This may be due to the variation in air temperature during this time. Observations of relative humidity at 1:30 pm are shown in fig 4.5. Maximum relative humidity noted in VFS1 is 55.4% and in VFS2 was 52.3%.Minimum relative humidity were 45.2% and 39.1% respectively.

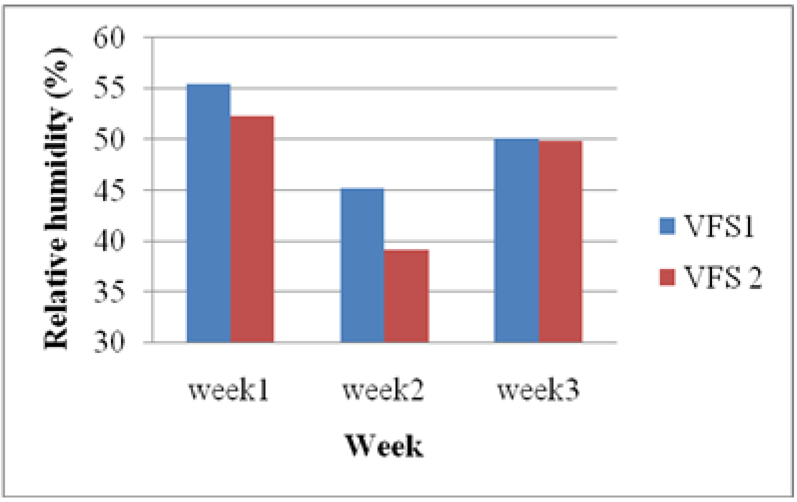

Fig 4.5 Variation of relative humidity in VFS1 and VFS2 at 1:30 pm.

A variation of 7% difference was noted in second week and 1 to 3% variation was observed in first and third week in both structures.

A variation observed in RH between two structures was less in 1.30 pm compared to 8.00 am. The values of relative humidity observed at 5 pm for the three weeks are shown in the fig 4.6. The relative humidity ranges between 52.5 to 66.5% within this three week. The maximum value obtained in the evening are 66.5% and minimum value is 55.4% in VFS1. And for the VFS2 are 61.9% as the maximum and 52.6% as the minimum. A variation of 2 to 4% was observed between structures.

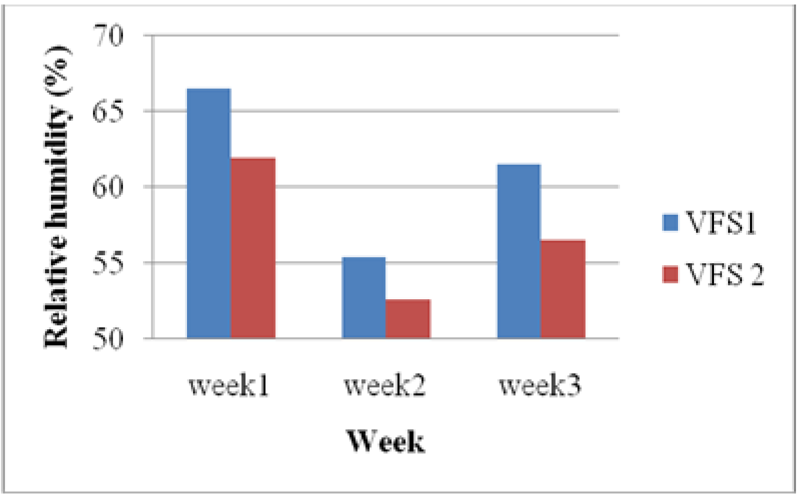

Fig 4.6 Variation of relative humidity in VFS1 and VFS2 at 5:00 pm.

The maximum value of relative humidity was observed in morning hours compared to noon and evening. The relative humidity was less in VFS2 compared to VFS 1 in almost all times and weeks. The relative humidity is slightly more for the VFS1 even though the air temperatures are almost same. This is because of the average air temperature of VFS1 is less than VFS2.

4.3 Light Intensity

The weekly average values for light intensity was calculated for 8:00 am, 1:30 pm and 5:00 pm respectively from the daily observed data. Measurements were taken using lux meter in the range B and range C. Observations were obtained from each tiers of both vertical farming structures. Fig4.7 shows the variations in light intensity of both VFS at 8:00 am. The maximum light intensity observed was 14898.7 lux in the VFS1 in the second week and minimum value measured is 6687.8 lux in the VFS1in third week. From the graph, it is clear that variation in light intensity was less in between the structures.

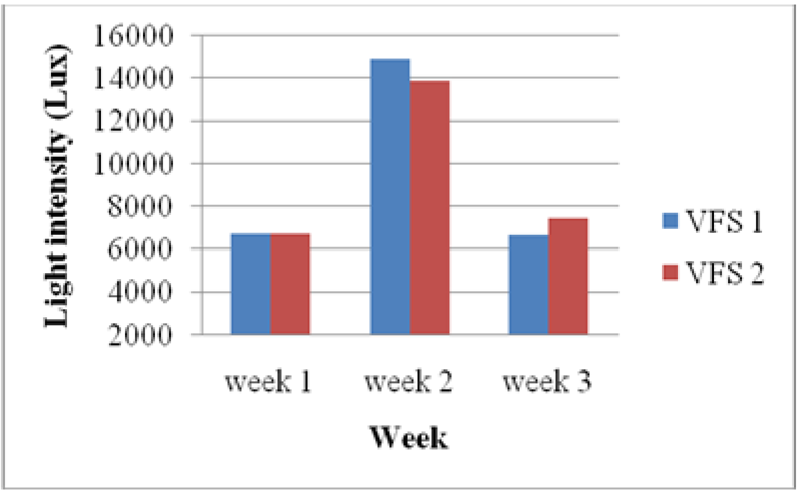

Fig 4.7 Variations in light intensity in VFS1 and VFS2 at 8:00 am.

Fig 4.8 shows the variations in light intensity of both VFS at 1:30 pm. From the figure it is clear that maximum intensity obtained at noon and that is 30487.2 lux in VFS1 in second week. The minimum measured value is 22599.9 lux in the VFS2 in third week. The light intensity ranges between 22599.9 to 30487.2lux. The variation in light intensity is more in second and third week. The maximum amount of light intensity occurred in noon due to North-South orientation. The air temperature was also observed high during noon hours.

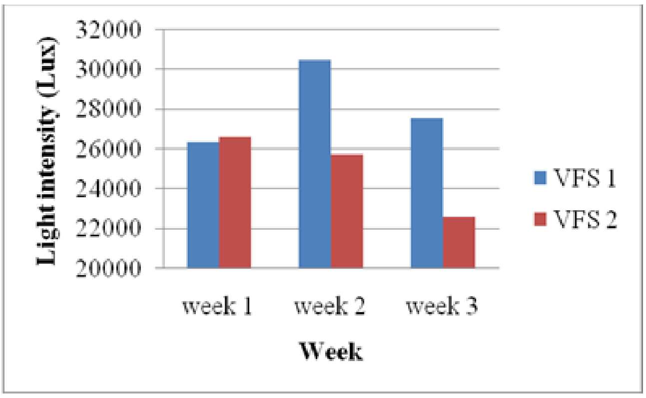

Fig 4.8 Variations in light intensity in VFS1 and VFS2 at 1:30 pm.

Fig 4.9 shows the variations in light intensity of both VFS at 5:00 pm. The maximum value of light intensity of 6000 lux was observed in VFS 1 in second week. The minimum light intensity of 4127.1 lux was measured from VFS2 in third week.

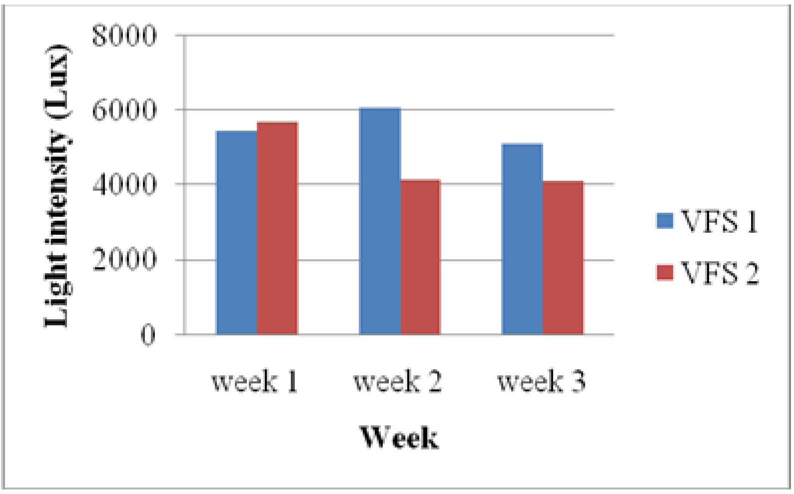

Fig 4.9 Variations in light intensity in VFS1 and VFS2 at 5:00 pm.

The light intensity was observed high at noon hours ranges between 20000 to 30000 lux compared to morning and evening hours. At 8.00 am, more variations in light intensity occurs and 5.00 pm, it ranges between 4000 to 6000 lux.

4.4 Moisture content of the rooting media

Moisture content is an important parameter for the optimization of irrigation requirement. Two rooting media of soilless and soil media were used for the study. Soilless media have good water holding capacity. Fig 4.10 shows the moisture content of the rooting media of various treatments in both VFS. The moisture content was measured from the rooting media at a depth of 6 cm.

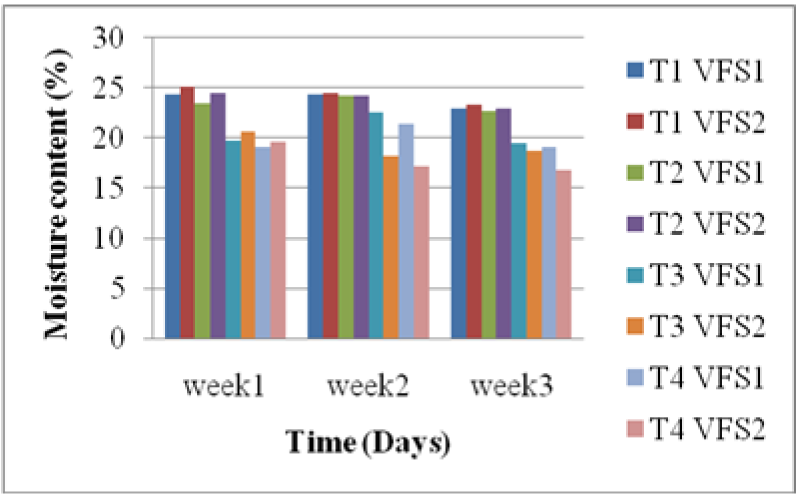

Fig 4.10 Moisture content of rooting media at different treatments

A trial was conducted with an amount of 1000 and 500 ml per day and was applied to each crop through drip in both soil and soil less media. As the depth of the rooting media was only 9 cm, this much amount of water caused water logging condition in the root zone and caused 30% and 20% of crop failure. The amount of water applied was then changed and fixed as 250 ml per day per plant. The moisture content was observed 24 hour after irrigation regularly for duration of three weeks. Analysing the fig 4.10, the treatment T1 in the VFS2 i.e., 100% irrigation with soil less media hold good moisture content. The maximum moisture content obtained was 25%. Treatment T2 also posses more moisture content in both VFS than T3 and T4 i,e with soil. The moisture content ranges from 20 to 25% in soil less media in both the structures 24 after irrigation. Moisture content retained by treatments T3 and T4 ranges between 15 to 20% i.e, with soil is less in both VFS while comparing with the treatments T1 and T2. The study showed that soil less media can hold 5 to 10% more moisture than soil media 24 hour after irrigation.

4.5 Biometric observations

4.5.1 Plant Height

The observations on height of the plants were taken in weekly interval. The height of selected plants from each treatment was observed for three weeks.

Maximum plant height at the end of 3rd week is observed in the T4 treatment of VFS2, i.e soil with 70% irrigation, and is about 42 cm followed by T3, soil with 100% irrigation, i.e about 38 cm. Minimum plant height of 11.8 cm was found in T1 treatment of VFS1, 100% irrigation in cocopeat and vermicompost. The growing pattern of the plants in both VFS is shown in Fig 4.11. By comparing the growth of the plants in both VFS, the VFS2 have more growth than VFS1.

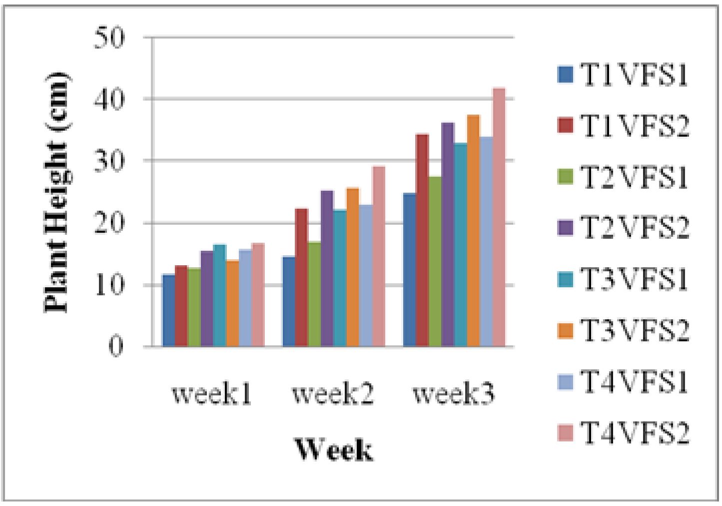

Fig 4.11 Variation of plant height in different treatments

4.5.2 Plant Girth

The observations on plant girth were first taken one week after planting. After that, the observations were taken in a weekly interval. For the last two weeks the girth of the plants was more in the VFS2. During the third week the girth of the plants in T4 of VFS2, ie. soil with 70% irrigation, increased to a higher value than corresponding values for the plants in VFS1. By analysing the data the increase in the rate of girth is more for the VFS2 between successive weeks. For the last two weeks the highest values 31 mm were observed for T4 of VFS2 and T3 of VFS1 i.e.,ie, soil with 70 % and 100% irrigation. The plant girths for T1, T2, T3 and T4 for the three weeks of VFS1 and VFS2 is shown in the Fig 4.12

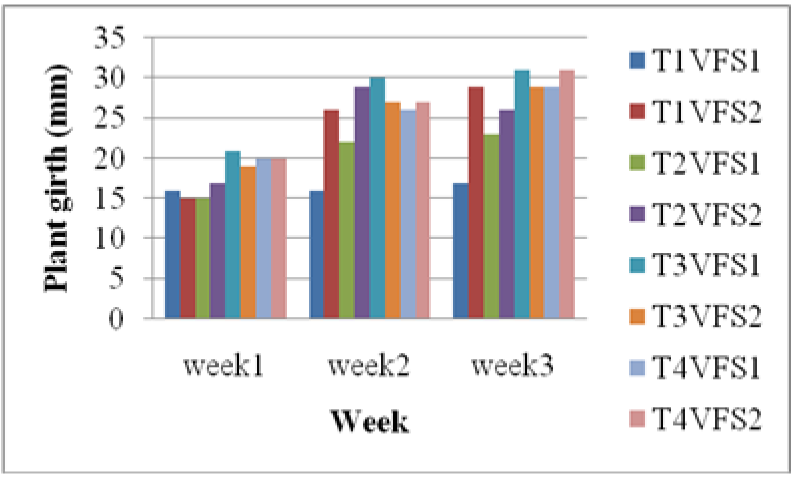

Fig 4.12 Variation of Plant girth in different treatments

4.5.3 Number of leaves

The observation on number of leaves was first taken one week after planting. After that, the observations were taken in a weekly interval.T4 exhibit better performance in VFS2 for the first two weeks over VFS1. T2 had highest no. of leaves in VFS1 during first two weeks. T3 had better performance under VFS2. The highest values were observed for T4 of VFS2 and T3 of VFS2 are 30 and 28respectively during the third week ie, soil with 70 % and 100% irrigation. The no. of leaves for T1,T2,T3and T4 for the three weeks of VFS1 and VFS2 is shown in the Fig 4.13. The percentage increase in number of leaves is more for T4 of VFS1 and VFS2.

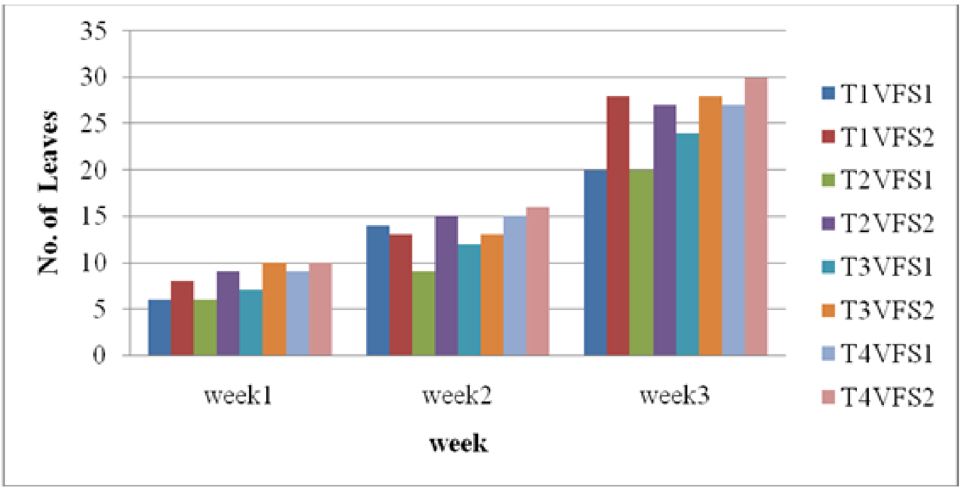

Fig 4.13 Variation in Number of leaves of plants in different treatments

From analyzing the data, it is clear that plant height, girth and number of leaves was more in VFS2 with 70% and 100% irrigation in soil.

4.5.4 Yield data

The observation on yield for amaranthus was taken one month after planting. The average yield of amaranthus in kg/ ha is shown in Fig 4.14.

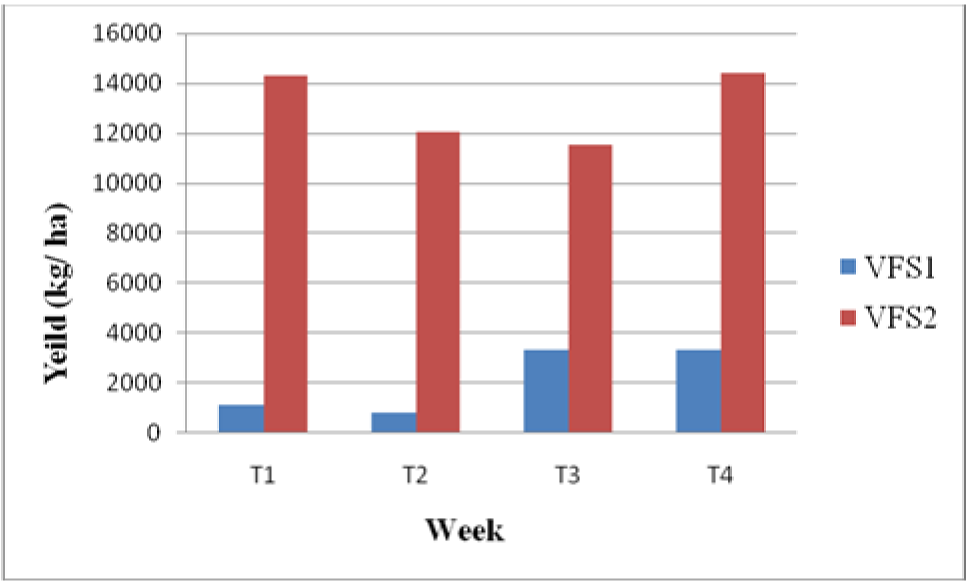

Fig 4.14. Yield of amaranthus from VFS1 and VFS2 under different treatments

The yield from T1 of VFS1 and VFS2 was 1145 kg/ha and 14285.7 kg/ha respectively. The highest yield obtained from the treatment T4 of VFS2 is 14386.7 kg/ha followed by T1 of VFS2. Comparing the yield from different treatments, T4 i.e., 70 % irrigation in soil of VFS2 followed by T1 i.e., 100% irrigation with vermicompost and cocopeat in the ratio 3:1 is showing highest yield compared to T3 and T2 in VFS2. Treatment T4 and T3 is almost showing similar yield which one is highest in the case of VFS1 ie., 70 % and 100% irrigation with soil. The moisture content observed in T3 & T4, retaining 15 to 20% of water was less compared to T2 and T1, retaining 20 to 25% of water 24 hour after irrigation. From this, it is clear that T4, 70 % irrigation with soil is the best treatment both vertical farming structures with similar climatic conditions even though moisture content was less.

Air temperature is more measured in VFS2 in almost all times, and maximum temperature is obtained in noon hours. The maximum temperature measured was 36.6ºC and minimum temperature recorded was 27.3ºC. Relative humidity is almost same for both VFS and more RH is obtained in morning. The relative humidity ranges in between 50-70%. Light intensity is varying from morning to noon hours. More light intensity is observed in noon, and that was 30487.2 lux. Moisture content of the soilless media is high compared to soil media. The soil less media can hold 5 to 10% more moisture than soil media 24 hour after irrigation.

Plant height is high for T4 treatment of VFS2 and the height recorded as 42 cm and Plant girth is also high for T4 treatment of VFS2 and that is 31 cm. Number of leaves is counted high for T4 (30) of VFS2 followed by T2 (29) of VFS1. Yield obtained from VFS2 also higher than VFS1. The yield from T4 of VFS2 was 14386.7 kg/ha and that followed by T1 of VFS2 was 14285.7 kg/ha. By analyzing all data, it is clear that plant height, number of leaves, girth and yield is more in T4, i.e, 70% irrigation with soil in vertical farming structure 2, if the structure is orienting in north-south direction.

CHAPTER V

SUMMARY AND CONCLUSION

The study entitled the "Performance evaluation of Vertical farming structures" was aimed at to compare the performance of existing VFS by orienting in North-South direction.

The site in the northern side of KCAET campus nearer to the staff quarters is selected for the installation of vertical farming structures. Both of the vertical farming structures (VFS) were oriented in North-South direction. The two structures were located at the same area for getting similar climatic conditions. The number of crops accommodated in VFS1 and VFS2 were 96.

Amaranthus was selected for trial and seedlings transplanted into the half splitted PVCs arranged in the three tiers of VFS1. In VFS2, grow bags were placed over platforms in three tiers. Grow bags of 15 cm x 30 cm were selected for planting the crops, so that 8 grow bags could be placed in the 183 cm x 20.5 cm sized platforms provided in the VFS2.

Two rooting media were used one is prepared by mixing cocopeat and vermicompost in 3:1 ratio and the other one is soil itself. Drip irrigation was provided for both the structures with the water source being the main water tank in the campus. 100% and 70% level of irrigation is applied for reducing the water use. Fertilizer application was done manually. The different rooting media were compared under VFS1 and VFS2 by observing the performance of crops grown. For the comparison of performance of crops climatic parameters as well as biometric observations were taken.

Climatic parameters such as air temperature, relative humidity and light intensity the morning, afternoon as well as in the evening at a fixed time for three weeks, and moisture content of rooting media was observed 24 hour after irrigation. Biometric observations of randomly selected crops in each treatment were taken once in a week.

The observations revealed that there are only slight variations in the temperature between the VFS1 and VFS2. The maximum temperature measured in VFS1 was about 27.9°C and in VFS2 about 28.2°C in the morning. Minimum temperature noted was 27.6°C in VFS1 and 27.3°C in VFS2. In the noon hours, the maximum temperature measured in VFS1 was about 33.7°C and in VFS2 about 36.6°C. Minimum temperature noted was 32.8°C in VFS1 and 34.4°C in VFS2. In the evening, maximum temperature at VFS1 was about 30.8˚C and at VFS2 was 30.6˚C.

Minimum temperatures observed in VFS1 were 28.7°C and 29.4°C for VFS2. Analyzing the observed values, it is clear that VFS2 has more temperature during three time periods. During the growing stage, the heat of respiration liberated by the crops also has a small role on this observed variation. In third week, both the VFS1 and VFS2 show almost same air temperature. After the full establishment of plants, heat was absorbed by the plants.

The relative humidity is slightly more for the VFS1 even though the air temperatures are almost same. This is because of the average air temperature of VFS1 is less than VFS2. At morning relative humidity is almost same for both structures. The highest values of relative humidity were observed in the morning time due to the cooling effects of plants combined with the least air temperature in the morning.

The structure is oriented in North-South direction, so the plants can absorb maximum light. During morning the right side of the VFS can harness more amount of light and the left side of the both structures get good amount of light in the evening. The maximum amount of light intensity is observed during noon. From the observed values it is clear that VFS1 get more amount of light compared to VFS2, because the VFS1 is relatively open into the atmosphere. The maximum observed value in the VFS1 is 30487.2 lux and that of VFS2 is 26626.2 lux.

Moisture content of the rooting media are analysed in treatment wise. Observed values indicate that the soilless media have good water holding capacity since it showing higher amount of moisture content. Treatment T1 has high moisture content because it is soilless media with 100% level of irrigation. Comparing T1 in both structures highest amount of moisture content is shown by VFS1. T4 treatment shows minimum moisture content since it is soil media with 70% level of irrigation. The study showed that soil less media can hold 5 to 10% more moisture than soil media 24 hour after irrigation.

The biometric observation for the trial with amaranthus, highest plant height was observed for T4 of VFS2 in the first two week period (16.8 cm, 29.2 cm). But the percentage increase in the plant height is more for T2 of VFS1 followed by T4 of VFS1 during the last two weeks. Plant heights of T3 of VFS2 (37.5 cm) and T4 of VFS2 (42 cm) are comparable. The highest girths were observed for both soil media of T3 and T4. The percentage increase in girth of the plant is more for T4 of VFS2 followed by T3 of VFS1. Girth of T4 of VFS2 and T3 of VFS1 (31 mm) are same.

After the third week, number of leaves in T4 of VFS2 is higher than T4 of VFS1 and followed by T2 of VFS1. The percentage increase in number of leaves is also more for T2 of VFS1. The number of leaves obtained in T4 treatment of VFS2 is 30 and minimum number of leaves is obtained in T1 of VFS1. Incase of yield, T4 had better performance under VFS1and VFS2. The maximum yield of T4 was observed in VFS2 was about 14393.5 kg/ha followed by 14154.2 kg/ha of yield is obtained from T1 of VFS2. The maximum yield get from T4 of VFS1 was 3333.3kg/ha.

The analysis of the experiment revealed that the treatment T4 shows better performance under almost same climatic conditions. T4 treatment is the plant with soil media and reduced level of irrigation. From this we can conclude that the irrigation is optimized with a saving of 30% water, gives maximum yield. Evaluating the overall performance of the structures, VFS2 shows better growth pattern and maximum yield. The orientation of the VFS can be changed according to climatic parameters, from this study it is clear that VFS can obtain maximum light by orienting in the North-South direction. The structure can be adopted for limited land area conditions and for the soils having drought, salinity and toxicity problems.

Scope of study

1.The study can be extended by providing arrow drippers.

2. The study can be extended by automating the vertical farming system.

3. The study can be extended by adopting in balconies or rooftops under different conditions.

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ABSTRACT

The study entitle "Performance evaluation of vertical farming structures" was taken up to compare the growth of amaranthus under different treatments on different vertical farming structures. The orientation of the both the structure was in north-south direction. For comparing the performance of plants under VFS1 and VFS2, climatic parameters as well as biometric observations were made. The analysis of climatic parameters suggested that adoption of VFS can modify the climatic parameters (temperature, humidity etc) considerably to provide a favorable climatic condition. The number of leaves, stem girth, plant height and yield varied between the treatments. T4 had the best performance in both VFS compared to T1,T2 and T3. The analysis of yield data showed that the highest yield was obtained for the treatment T4 of VFS1and VFS2. The study revealed that T4 (soil media) is the best rooting media with 70% of level of irrigation for growing crops in VFS2 compared to T1 (100% level of irrigation with soilless), T2 (70% level of irrigation with soilless media) and T3 (100% level of irrigation with soil media). The study suggested that VFS2 orienting in North-South direction, can be recommended more precisely for the conventional farming practice on limited land area compared to VFS1 due to the lack of proper drainage.