DEVELOPMENT AND EVALUATION OF A VERTICAL FARMING STRUCTURE

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PROJECT REPORT

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DECLARATION

We hereby declare that, this project entitled **"DEVELOPMENT AND EVALUATION OF A VERTICAL FARMING STRUCTURE**" 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 **"DEVELOPMENT AND EVALUATION OF A VERTICAL FARMING STRUCTURE**" is a record of project work done jointly by Akhila Tom Thekkanady, Shaheemath Suhara.K.K and Vidhya.C 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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Dedicated to

Farmers of Tomorrow

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SYMBOLS AND ABBREVIATIONS

AD	Anno Domini
BC	Before Christ
C	Carbon
CEA	Controlled Environment Agriculture
cm	Centimeters
CO_2	Carbon dioxide
°C	Degree Celsius
dB	Decibel
dS/m	Deci Siemens per meter
Dept.	Department
DLR	Dockland Light Railway
EU	European Union
EVFS	Existing vertical farming structure
eg.	Example
et al	And others
Fig.	Figure
ft	Feet
FV	Fabricated vertical farming structure
^{o}F	Degree Fahrenheit
g	Gram (s)
/m^2	Gram (s) per square meter(s)

GHG	Green House Gas
ha	hectare
hp	horse power
hrs	Hours
i.e.	That is
inch	inches
j.	Journal
K	potassium
KAU	Kerala Agricultural University
KCAET	Kelappaji College of Agricultural Engineering And Technology
KCl	Potassium 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 Conservation Engineering
m	Meter (s)
m^2	Square meter (s)
ml	milli litre
mm	millimeter

N	Nitrogen
No.of	number of
P	Phosphorus
PVC	Poly Vinyl Chloride
sec	Second
ton/acre	Tone(s) per acre (s)
U. S	United States
UV	Ultra Violet
USDA	United States Department of Agriculture
V	Volt
VF	Vertical Farming
VFS	Vertical Farming Structure
W	Watts
&	and
°	Degree (s)
/	Per
%	percentage
′	Minute (s)
″	second

INTRODUCTION

CHAPTER I

INTRODUCTION

Agriculture is a fundamental human activity and is inseparable from human life. Modern day agriculture is a major contributor to a large range of environmental problems the world is facing today. Agricultural runoff, ecosystem degradation and loss, use of fossil fuels, food wastage, artificial irrigation and use of the world's fresh water supply are few in a long list of issues that needs to be addressed if current agricultural practice is to be made truly sustainable in future.

Traditional farming takes a huge toll on the environment. Negative environmental effects of traditional farming include the steady decline of soil productivity, over-consumption of water (including water pollution via sediments, salts, pesticides, manures, and fertilizers), the rise of pesticide-resistant insects, dramatic loss of wetlands and wildlife habitat, reduced genetic diversity in most crops, destruction of tropical forests and other native vegetation, and elevated levels of carbon dioxide and other greenhouse gases. And as urban sprawl continues unabated, vast swaths of productive farmland are being eliminated. Estimates place the amount of farmland lost due to development since 1970 at a whopping 30 million acres.

By the year 2050, nearly 80% of the earth's population will reside in urban centers. Applying the most conservative estimates to current demographic trends, the human population will increase by about 3 billion people during the interim. An estimated 109 hectares of new land is to be needed to grow enough food, if traditional farming practices continue as they are practiced today. At present, throughout the world, over 80% of the land that is suitable for raising crops is in use. 20% of the land has been laid waste by poor management practices.

As a solution, an increasing number of horticulturalists and entrepreneurs are turning to controlled-environment agriculture (CEA), and the related practice of vertical farming. While not a total panacea, these high-tech farms are doing much to address many of the problems associated with conventional farming practices.

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. Vertical farming concept is an ongoing project that has grown over the last decade. Columbia University is 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. The concept, modified by dedicating high-rise buildings in urban environments for food production purposes, is called vertical farming. This method of vertical farming will include the production of freshwater fishes, crustaceans, and molluscs, 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.

The aim of this concept is to follow the patterns of past civilizations and inhabitants; land was abandoned when it was no longer ecologically useful. Thus, the abandoned area will be left untouched to naturally rehabilitate and experience re-growth. Vertical farming will provide an alternative agricultural venue, allowing land that has been depleted to take a break and repair itself with natural growths. Henceforth, the concept of vertical farming will provide the alternative ecosystem for most of the world's traditional food requirements, in order to give room for most of the agricultural lands to rehabilitate it.

1.2 How Will Vertical Farming Work?

According to scientific calculations, a single vertical farm that will occupy about one square block of a city and elevated up to 30 stories can provide enough food to supply the needs of about 10,000 people. Constructing these vertical farm units will develop a closed system where waste products, air, water and minerals, needed by plants and vegetables to thrive, will be recycled within the building. It aims to generate energy, maintain a pesticide-free farming technology, effective waste management as a means of sustaining food production all within one vertical farm building. Channeling the city's wastes into its system which will undergo bioremediation process makes it a feasible integration to the farming technology. There is still a long way to go in constructing these vertical farms, since the aim is to generate greater yields for every square foot that the system uses.

1.3 Vertical Farming Advantages

- 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.

- Year-round crop production

Unlike traditional farming in non-tropical areas, indoor farming can produce crops year-round. All-season farming multiplies the productivity of the farmed surface 4 to 6 times depending on the crop. With some crops, such as strawberry, the productivity can be 30 times more.

- There is no crop failure due to floods, pests and droughts

Because vertical farming provides a controlled environment, the productivity of vertical farms would be mostly independent of weather and protected from extreme weather events. Vertical farming eliminates the agricultural runoff.

- Conservation of resources

Every 1 acre indoors is equal to an average 4-6 outdoor acres depending upon the species. This is due to the fact that many layers of plants can be stacked on top of each other and elimination of other causes of crop failures caused by the outside environment.

- Vertical farming can avoid deforestation and desertification caused by agricultural encroachment on natural biomass.

- Vertical farming lets crops be grown closer to consumers; it would substantially reduce the amount of fossil fuels currently used to transport and refrigerate farm produce.

- Producing food indoors reduces or eliminates conventional tillage, planting, and harvesting by farm machinery, also powered mostly by fossil fuels.

- Burning less fossil fuel would reduce air pollution and the carbon dioxide emissions that cause climate change, as well as create healthier environments for humans and animals alike.
- Production of organic and healthier crops

In an enclosed building, optimum temperatures can be controlled and maintained, allowing for healthier, faster growing plants.

- The controlled growing environment reduces the need for pesticides, namely herbicides and fungicides.

- Impact on human health

  Vertical farming greatly reduces the incidence of many infectious diseases which are acquired by the agricultural interface.

- 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.

- Urban growth

  This would allow for large urban centers that could grow without destroying considerably larger areas of forest to provide food for their people. Urban centers can now be considered sustainable environment. It converts abandoned urban properties into the food production centers.

- 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.

- Vertical farming creates new employment opportunities.

- Vertical farming offers a realistic possibility of the economic improvement for tropical and subtropical least developed countries (LDC) and can reverse the trend in population growth of LDCs, since they adopt urban agriculture as a strategy for sustainable food production.

- Water conservation and recycling.

- Favours the biodiversity

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

1. To fabricate a VFS suitable for homestead
2. To evaluate the performance of the fabricated VFS
3. To compare the performance of newly fabricated VFS with the existing one

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Most challenging task for agricultural sciences today is to ensure for continuous and enough supply of food to the growing human civilization. Urban centres throughout the world have experienced substantial increase in population; this growth is accompanied with change in food habits and rising concerns for food quality. Thus, increasing global trade and easy access to chemicals and technology has contributed to changes in agricultural systems. Recent trend in agriculture has seen rise in organic agriculture, vertical farming and intensive agriculture to accommodate the demands of the rising world population and address the emerging concern for environmental issues. Vertical farming shall help in meeting the food & other demands of the rapidly growing urban population. Vertical farming will be a worthwhile project because it replaces the thousands of crop acres by simple buildings, it recycles water, and it protects the food from weather anomalies.

2.1 Constraints in Improving Agricultural Production

Day Phillip (2009) studied about the 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. If contamination proves too cost-prohibitive to remedy, contained systems can be used to bypass exposure. These include both soil covers and contained food-production methods such as raised beds, hydroponic or aquaponic systems, and vertical or container-based gardening systems.

Adeleke Salami (2010) investigated the trends, challenges and opportunities of sub-sector in East Africa through case studies of Kenya, Ethiopia, Uganda and Tanzania. This study finds that at the national level, weak institutions, restricted access to markets and credit and inadequate infrastructure causes constrained productivity growth of smallholder farming.

Estes *et al*. (2010) showed that raised beds filled with fresh compost can become re-contaminated over time, due to runoff and windborne dust from contaminated areas.

Fengxia Dong (2010) examined the credit constraints which affect agricultural productivity and rural household income in China. The findings of the study suggested that under credit constraints, production inputs, along with farmers' capabilities and education, cannot be fully employed. By removing credit constraints, agricultural productivity and rural household income can be improved.

2.2 Urban agriculture

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.

Gilhooley (2002) conducted an experiment and found that the participants of who worked in an environment with plants 12% more productive were less stressed than those who worked in an environment with no plants.

Caton Campbell *et al*. (2003) reported that to mitigate the challenges and to create more secure land tenure for urban gardeners and farmers, foundations can provide financial support for community land trusts, conservation groups, or urban agriculture related organizations to secure land tenure through ownership or long-term agreements.

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.

Mubvami and Mushamba (2006) reported that an important determinant of urban agriculture's long-term success is the availability and access to space for food production and processing purposes.

Tixier and Bon (2006) did a study on urban horticulture. They revealed that the success of urban agriculture, like that of traditional rural agriculture, is dependent on a variety of factors, including weather, light, labour, agricultural skills and knowledge; capital and operating funds; access to land or other growing space; land tenure; access to healthy, uncontaminated soil or other growing medium; and access to water.

Richard Shetto and Marietha Owenya (2007) studied about the conservation agriculture as practiced in Tanzania. Conservation agriculture is a good way to farm, reduce soil erosion, and increase water infiltration, soil organic matter and, ultimately, food security. It requires radical change in farmer and extension staff attitudes. This requires patience and combined effort from all stakeholders involved in conservation agriculture.

Raja *et al*. (2008) suggested that a community-based food-systems approach has the potential to simultaneously address issues of food security, public health, social justice, and ecological health in local communities and regions, as well as the economic vitality of agriculture and rural communities. Such an approach emphasizes, strengthens, and makes visible the relationships among producers, processors, distributors, and consumers of food at the local and regional levels.

Teig *et al.* (2009) concluded that urban agriculture can foster community building, mutual trust, sharing, feelings of safety and comfort, and friendships that translate into a collective investment in the common good of a neighborhood. It can also serve as an alternative vacant property reuse strategy to decrease or prevent crime, trash accumulation, illegal dumping, littering, juvenile delinquency, and fires, and as a catalyst for additional community development activities and positive place-based programs

Vitiello *et al*. (2009) studied on community gardening in Philadelphia. They revealed that subsistence production reduces food expenditures and makes household income available for other purposes. For example, in 2008, community and squatter gardens in Philadelphia produced summer vegetables worth approximately $4.9 million, an amount greater than the combined sales of all of Philadelphia's farmers markets and urban farms.

Clurfeld (2011) reported that over the next few years large-scale CEA operations will begin to supply more food to New Yorkers as well as residents of other cities, including Montreal.

Zuhal Kaynakci Elinc (2013) reported that increasing the availability of natural vegetation in urban areas is also very important for inner city wild life. More an area is covered with vegetation, the higher the potential of maintaining different kinds of wild life.

Amanda Lenhardt *et al.* (2014) described the factors that have enabled 200,000–300,000 hectares (ha) of degraded land in Burkina Faso to be brought into productive use through the application of improved traditional farming techniques. Three main factors have contributed to achieving progress in sustainable farming in a context of environmental stress and limited resources. First, farmers themselves have been adapting these farming techniques for generations and local knowledge of suitable and efficient methods was crucial. Second, information about the improved sustainable techniques was effectively diffused through existing community networks. Third, the adoption of these improved techniques was encouraged by the provision of financial support for the initial labour and start-up costs, which was essential for many of the poorest farmers.

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 isn't sufficient or if drainage routes become blocked, green roofs can cause some flat roofs to 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.

Baumann (1986) found that green walls can reduce wall temperature as much as 15°F which results in significant air conditioning savings.

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 16^{th} - 17^{th} 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.

Fjeld *et al. (*1998) conducted a study on the effect of indoor foliage plants on health and discomfort symptoms among office workers. The study showed that the plants reduce wind-speed also they prevent dust with wet environments which created with their roots and leaf. By means of this event, plants bring about extinction to harmful microorganisms with on site sap and juice. Air quality improvement from plants has been shown to reduce coughs by thirty percent and dry throat and irritation by twenty-four percent also, the plants clean the office air by absorbing pollutants into their leaves and transmitting the toxin to their roots, where they are turned into food for the plant.

Peck *et al.* (1999) reported that the beauty of a green wall (covering concrete and steel) can rejuvenate our minds and physical fatigue was greatly reduced. The presence of plants in the office not only reduces stress but also helps to increase productivity of workers. They also analyzed that VF causes improved air quality, due to the reduction in the rate of smog formation and the ability of vegetation to filter or absorb certain pollutants out of the atmosphere. The study also found that the application of vertical gardens is shown to increase property values by dramatically increasing the amenity of buildings, and establishing higher public acclaim, transforming them into recognizable landmarks.

Dickson Despommier (2001) 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.

Dunnett and Kingsbury (2004) found that soil and plants which were used for arrangements in Vertical Gardens had a voice absorption feature.

Evan Bromfield (2004) explained that the urban vertical farming is an application of controlled environment agriculture with ramifications even beyond helping feed the world's projected 9 billion in 2050. This is because of how much better it is than industrial agriculture, especially in these three ways: production efficiency, economic resilience, and ecological sustainability. There are clear efficiency, resiliency, and environmental advantages of vertical farming over traditional agriculture. There are even more advantages like supplying vegetables with species-specific nutrients and environmental conditions; something only the precise controls of vertical farming allow. This means that no excess compound will contaminate the plant and that nothing is wasted.

Elhadj (2005) conducted experiments in achieving water and food self-sufficiency in the Middle East. The experiment reported that recent decades have seen food sovereignty being sought by many nations and recommended by many think-tanks in view of the volatility of food prices. This is seen especially in geographical regions where purchasing power is high but agro-climatic factors too hostile for conventional agriculture, like in Deserts, Taigas and Tundras. VF could generate this sovereignty to a certain extend.

Martius *et al.* (2005) revealed through their study that at least high value fruits and vegetables cultivated in Vertical Farms has the potential to take some pressure from agriculture whereby, fertile lands can be utilized for cereal, fodder, fiber and bio-fuel production. VF may additionally create sustainable environments for urban centers purifying the air and providing a positive psychological effect on urban populace, who are often deprived of greenery.

Richard (2005) showed that the biggest threat to VF is skepticism from business and academia, and it is not entirely unfounded. Till date no project has practically demonstrated the viability of a VF at this scale, most exist in small research initiatives or as concept drawings by architects. Therefore it is imperative that initiation leave alone acceptance would require convincing at different levels and hence requires some serious action research.

Kor Kamonpatanal and Pongpun Anuntavoranich (2007) studied to find some relevant variables to vertical farming. 15 main variables were identified as being significantly relevant to the vertical farming concept. Which are food quantity, food quality, accessibility, food miles, city self reliance, economic feasibility, variables for plant survival, start-up cost, efficiency, cost/benefit, plant method, market need, plant selection, efficiency to reduce heat, energy and environmental management. These variables will be utilized in the future design of vertical farming applications in the city.

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.

Jacobs (2008) conducted a study about, benefits and design green walls technology. The report introduced several types of vertical gardens like modular trellis panel system, grid and wire-rope net systems, living wall systems, landscape walls and modular living wall system.

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.

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.

Dickson Despommier (2010) explained the vertical farming concept and also reducing the impact of agriculture on ecosystem functions and services. According to him to meet the demand of growing population, requires additional hectares of land. But the quantity of additional arable land is simply not available. Without an alternative strategy for dealing with just this one problem, social chaos will surely replace orderly behavior in most over-crowded countries. Novel ways for obtaining an abundant and varied food supply without encroachment into the few remaining functional ecosystems must be seriously entertained. One solution involves the const ruction of urban food production centers - vertical farms – in which our food would be continuously grown inside of tall buildings within the built environment.

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.

Facharbeit von (2011) pointed out that the biggest advantage of vertical farming is the space advantage. Furthermore, there is no wastage of water, crops are not exposed to extreme weather conditions, there is a reduction of CO_2 emissions and new recycling techniques seem to be ecologically friendly.

Germer *et al.* (2011) found that a controlled environment is unaffected by seasonal variation, opening up the possibility of multiple harvests a year , compared to outdoor farming that´s typically restricted to a single harvest a year this is a dramatic increase of production output potential. In a controlled environment the grower will be unaffected by weather fluctuations, drought and floods, avoiding the frequent loss of crops due to these factors commonly seen in outdoor agriculture.

Kretschmer *et al*. (2011) found that vertical farming is a worthwhile project because it replaces the thousand of crop acres by simple buildings, it recycles water, and it protects the food from weather hazards.

Levenston (2011) conducted a study on vertical farm of Suwon, a South Korean city. The facility was three stories in height totaling an area of 450 m^2. Almost 50% of the energy requirement was supplied through renewable resources like geothermal and solar arrays, which was mainly necessary for heating, cooling and artificial lighting requirements. Lettuce was being cultivated through careful regulation of light, humidity, carbon dioxide and temperature.

Alexandratos and Bruinsma (2012) reported that by the application of vertical frames and multiple stacks, the basic ground area of the building (2500 m^2) is increased 37 times to an expanded plant area to a total of 92,718 m^2, comprising of a total of 116 stacks through 25 floors. This results in a total production of 3,573.41 tons of edible plant biomass. However, for this only 2500 m^2 is being used, so if we grew all those crops proportionately on the same 2500 m^2 this means multiplication of the yields by a factor of 516. This makes Vertical Farming a viable candidate, at least theoretically for our race to multiplying the food production by 60% by 2050.

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).

Dickson Despommier (2013) studied about the controlled farming agriculture (CFA). He found that In the past 5 years, with the advent of spectrum-specific, higher efficiency light emitting diode (LED) grow lights, together with computer-assisted control systems for monitoring and delivering precise amounts of nutrients, adjusting the pH, temperature, and oxygen content of the nutrient solution, and for assessing the growth and overall health of each crop, CEA has rapidly evolved into a commercially viable approach for the large-scale production of a wide variety of crops in close proximity to, or even within, urban centers

Endogen (2013) found that approximately 1 square foot of vegetated wall area will filter the air for approximately 100 square feet of office area. Considered in very general sense, planting one wall of any house which situated 50 houses on the street is equal to plant 50 trees on this street.

Peter Moller Voss (2013) revealed that concept of Vertical farming is undoubtedly a promising one. It successfully combines the needs for an environmentally sustainable way of conducting agriculture with economic and resource efficient means of production. Human industries have long been characterized by a linear use of our natural resources, an open loop, in which resources move through the system only to become waste in the end. Vertical farming instead, emphasizes a nonlinear use of resources, successfully integrating the principles of closed loop systems where waste become inputs for new processes, to create a futuristic and truly sustainable method to conduct industrial agriculture. Being the novel concept that is Vertical farming, it´s best viewed as a work in progress.

Anirudh Garg and Rekha Balodi (2014) conducted a study to know the suitability of vertical farming and in the growing population. They found that these emerging technologies are required to be used judiciously to meet the demand of growing population. The concept foresees the cultivation of fruits, vegetables, medicinal, fuel producing plants and other plant products in the cities and their sales directly within the cities, thereby reducing the transportation costs and efficient utilization of land and water resources. Vertical farming and can be adopted as the viable alternatives for the conventional agriculture to meet the changing demands and needs of mankind.

M.Jegadeesh and Dr.J.Verap (2014) described that the vertical farming has to be practiced when there is unavailability of land and other requirements for the perfect structure of farming mode. The resources used in this vertical farming system where the windmill used to generate electricity for the water pumping system, also these windmills are kept at the top of the skyscraper to gather air source and other energy resources were added additionally such as solar energy for the purpose of generating the artificial light source to the crops for the high yielding.

Prof. Joel L. Cuello (2015) studied about the relevance of vertical farming. According to him most of the Vertical Farming concepts and designs are mainly based on those for conventional buildings, making Vertical Farms. He concluded as to accelerate growth and development of the vertical farming industry requires the standardization of the vertical farming platform or operating system. For that he introduced minimally structures, modular and prefabricated vertical farming designs.

2.4 Climatic influence of vertical farming

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.

Gaudet (1985) found that a 10º F reduction in the outside air temperature achieved through the judicious arrangement of shade trees (green roofs and vertical gardens), can reduce energy consumption for air-conditioning by 50-70%.

Abernathy (1988) conducted a study on roof spray cooling system and showed that if vegetation is situated so as to cover building surfaces then evaporative cooling can reduce the need for air conditioning by reducing the air temperature immediately adjacent to the building. Artificial evaporative cooling systems have been shown to reduce air conditioning by 20-25%.

Wilmers (1988) indicated that in Germany, the vertical garden surface temperature was 10 ^{0}C cooler than a bare wall when observed at 1:30 PM in September.

Holm (1989) conducted a study on thermal improvement by means of leaf cover on external walls. The result showed that for a building consisting of two 10mm fiber-cement sheets with 38mm of fiberglass insulation, a computer simulation estimated that a vertical garden reduced summer daytime temperatures on the surface by 5 ^{0}C. These results are not as dramatic as the cooling effect on a horizontal surface, such as a roof, but given the amount of wall space in urban areas, the potential impact of vertical gardening is expected to be quite dramatic.

Liesecke *et al*. (1989) reported that under a green roof, indoor temperatures (without cooling) were found to be at least 3-4°C (5-7°F) lower than hot outdoor temperatures between 25-30°C (77-86°F).

Mc Pherson *et al. (*1989) concluded in their study that vegetation can reduce the use of air conditioning through shading and insulating a surface. In previous tests, it has been estimated that shading from trees might reduce energy usage from 20 – 30%.

Hooker and Hendricks (1994) showed that a 12 cm layer of substrate can reduce sound by 40 dB and a 20 cm can reduce sound by 46 dB (with some reductions as high as 50 dB).

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.

Johnston and Newton (1996) showed that people living in high-density developments are known to be less susceptible to illness if they have a balcony or terrace garden due to the additional oxygen, air filtration and humidity control supplied by plants.

The studies conducted by Stifter (1997) in Berlin showed that rooftop gardens absorb 75% of precipitation that falls on them, which translates into an immediate discharge reduction to 25% of normal levels. Generally, summer retention rates vary between 70-100% and winter retention between 40-50%, depending on the rooftop garden design and the weather conditions.

Taha *et al.* (1997) conducted a study on urban climates and heat islands. The study concluded that vegetation will reduce energy emissions through reductions in the urban heat island, through shading windows from direct sunlight and through insulation from in both the winter and summer. Reducing energy usage directly on a particular building will reduce emissions of many pollutants into the atmosphere, but the indirect effect of reducing the urban heat island will also have an impact on urban air quality. In Southern California, simulation models have suggested that reducing the urban heat by 2˚C would be equivalent to converting half of the motor vehicles to zero-emission electric engines.

Mercier (1998) reported that green roof and vertical garden technologies can provide an effective and proven method for governments, companies and building owners to reduce these GHG emissions through direct shading of individual buildings, improving insulation values and reducing the urban heat island effect.

Palomo (1998) conducted a study on analysis of the green roofs cooling potential in buildings. The computer simulation of green roofs indicated that they could improve the thermal performance of a building by blocking solar radiation and reducing daily temperature variations and annual thermal fluctuations or by reducing heat flux through the roof.

Sailor (1998) reported that a lower fraction of vegetative cover in the city reduces the available moisture to direct incoming solar radiation towards evapotranspiration. The non-vegetated surfaces absorb the incoming solar radiation and reradiate it as heat. This heat artificially elevates urban temperatures, a phenomenon known as the urban heat island. The study also showed that a significant reduction in the urban heat island could be achieved in the Los Angeles basin with a 1% increase in vegetation.

Thompson (1998) reported that in Portland a 100mm (4in.) green roof could absorb a full inch of rainfall during a summer rain event (when the soil started out fairly dry) before water started to runoff. This storm water retention potential of rooftop gardens has led to a bonus density incentive programs in Portlan d for developers who install a green roof. Similar statistics do not exist for vertical gardens, but it would vary by design.

Groom *et al*. (2005) reviewed that one of the major benefits of vertical farming in urban centers is the gradual repair of these ecosystems. Translocation of food production to vertical farms would relieve the land currently used for agricultural purposes allowing for large scale ecosystem restoration. In many cases all it would take is simply abandoning the land and given time, nature will repair itself. Ecosystem re-growth will increase nature´s own buffering capacity, resilience and resistance to disturbance and pollution, increase biodiversity and carbon sequestration to name a few. Restoring ecosystem functions and services might very well be one of the most potent means we have to turn the negative spiral of climate change around, opening up the possibility of a brighter, cleaner and less polluted future.

Ellis (2012) reported that the architecture of the VF building is a key as it can be constructed to optimize light input according to seasonal and daytime variation as well as taking advantage of the simple laws of physics to maximize climate control and ventilation without the use of external power sources needed. However, regardless of how optimal the architecture is fitted, extra lighting and climate control will most likely be needed.

2.5 Drip irrigation system

Robert F. 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.

Mohamed Thabet (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.

B. Chennakesavulu and H.V. Hemkumar (2014) conducted a performance evaluation on the drip irrigation system. Two of the important design parameters pressure and rated discharge of the emitters are measured for different laterals in drip systems .The evaluation was taken up to check whether the operation of the drip systems is under the limits of the standards or not. The study revealed that all the fields are performing well in terms of discharge of emitters but a few fields with less pump size than the required fail to develop the required pressure.

2.6 N-P-K Fertilizer

R. M. Mohr *et al.* (2007) described the influence of nitrogen, phosphorus and potash fertilizer application on oat yield and quality. The study indicated that a plant-available N supply of approximately 100 kg N ha–1 was sufficient to achieve optimum grain yield. Applying additional N above this level did not result in further yield increases, and may result in declines in physical grain quality and increases in lodging. Oats were also responsive to P application, increasing yield were observed in only one-third of the site-years at locations with dry, cool early season conditions combined with low to moderate soil test P. Small improvements in grain yield (88 kg ha–1) and quality were also achieved with the application of 33 kg K ha–1 as KCl on soils with moderate to high soil test K levels.

2.7 UV sheets

Carlos A. Mazza *et al.* (2000) examined the functional significance and induction by solar radiation of ultraviolet-absorbing sunscreens in field growth soyabean crops. They found significant differences in UV penetration among cultivars with different levels of leaf phenolics, and between plants grown under contrasting levels of solar UV-B. They concluded that phenolic sunscreens in soybean are highly responsive to the wavelengths that are most affected by variations in ozone levels, and that they play an important role in UV protection in the field.

Claire Shaddick (2000) explained that there are worthwhile benefits in growing asparagus under protection in terms of yield, quality and season extension. It appeared that the crops grown under the standard or UV-opaque films have performed as well as, or in some cases better than, those growing under other spectral filter films.

Alberto Fereres *et al.* (2003) conducted a study to evaluate the impact of a UV-photoselective film on the population density of insect pests and the spread of virus diseases in horticultural crops. The study showed that UV-absorbing films are a very good alternative to reduce the need for insecticide sprays and effectively protect lettuce crops from insect pests and insect-borne virus diseases.

Beatriz M. Diaz and Alberto Fereres (2007) found that Ultraviolet-Blocking Materials act as a Physical Barrier to Control Insect Pests and Plant Pathogens in Protected Crops .UV-blocking materials have properties to filter the UV radiation (280-400 nm) interfering with the vision of insects and in consequence, their behaviour related with movement, host location ability and their population parameters. The exclusion of part of the UV radiation within the greenhouse environment has a dramatically incidence on insect orientation, movement and on the spread of insect-transmitted viral diseases. In the same way, the impact of UV-absorbing materials on population dynamics of natural enemies, pollinators and crop yield needs further investigation.

K. Zuk-Golaszewska, M.K. Upadhyaya(2014) found the effect of UV-B radiation on plant growth and development by conducting an experiment in the greenhouse. The different doses of UV-B radiation applied to the two species Avena fatua and Setaria viridis induced changes in leaf and plant morphology. It was a decrease of plant height, fresh mass of leaves, shoots and roots as well as leaf area. Besides, it caused the leaf curling in both of the species. The significant differences between Avena fatua and Setaria viridis in the studied traits were mainly due to the tillering ability of the species. The content of chlorophyll varied considerably. The average values of leaf greenness (SPAD units) for oats were about 43 while for green foxtail 32, respectively. U-VB did not reduce leaf weight ratio, shoot dry matter, and shoot to root ratio and leaf area ratio.

Solaiman A.H.M et al. (2015) described the effect of Partially UV Blocking Films on Xanthomonas axonopoides Pv. Citri Causing Citrus (Citrusaurantifolia) Canker. Plants treated with different wavelengths of UV radiation showed gradually decreasing disease incidence and severity with decreased temperature and relative humidity.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter describes the materials used and methods employed for the project under the title “Development and Evaluation of a Vertical farming Structure” conducted in the Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, Kerala.

3.1 Location 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 42.1 ˚C and mean minimum temperature of the area is about 22˚C. The experimental study was conducted during October 2015 to January 2016.

3.2 Fabrication of VFS

Mild steel tubes and rods of different dimensions were used for making the frame and roof of the structure. 36 grow bags of dimension of 15 cm x 15 cm were placed in the frame. MS flats of 3/4” x ⅛” were used as a seating for grow bags. UV polythene sheets of 200 micron were used as a covering material for the roof. To supply the adequate quantity of water with minimum losses, drip irrigation was adopted. The material required for the fabrication of VFS is shown in the table 3.1.

Table 3.1. Materials used for construction of VFS

Material	Quantity
1" square tube	24 m
3/4" square tube	36.5 m
1/2" MS rod	38 kg
3/4" x⅛" MS flat	24m
Turpentine	500 ml
Metal primer	500 ml
Enamel paint	500 ml
UV sheets (200 micron)	9 m^2

The materials required for providing irrigation are shown in the table 3.2.

Table 3.2. Materials used for drip irrigation

MATERIAL	**QUANTITY**
PVC pipe (4 inch)	1.2m
PVC pipe (3/4")	5m
Micro tube	5m
Laterals	6m
Emitters (4 lph)	36 nos
Take off (16 mm)	12 nos
Washers	12 nos
T connector (16mm)	20 nos
Micro tube connector	50 nos

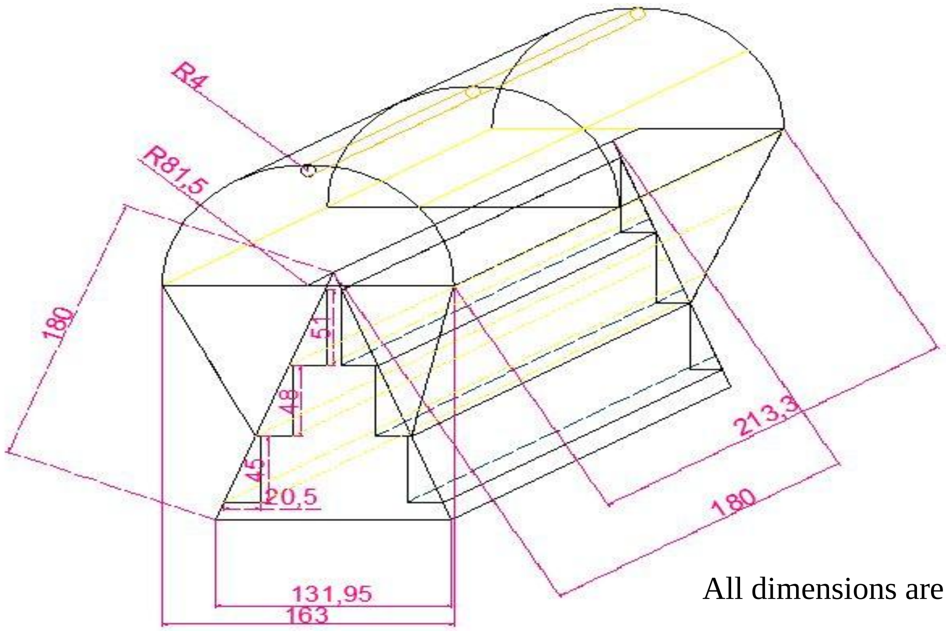
¾” MTA	2
¾ ”ball valve	1
¾” bend	4
End caps	8 nos

Materials used for planting is shown in the table.3.3

Table 3.3. Materials used for planting

MATERIALS	**QUANTITY**
Grow bags (15 x15cm)	36 Nos.
Cocopeat	1 block
Seed	20 g

3.2.1 Experimental setup



All dimensions are in cm

Fig.3.1. Fabricated vertical farming structure

The VFS had a dimension of 213 cm x 163 cm x 213.3 cm. It was a platform like structure consisting of 3 platforms on each side which project inwards. The seating for the grow bags were provided by fixing MS flats in between the square tubes. Each platform can accommodate 6 grow bags of size 15 cm x 15 cm, so that 36 grow bags can be placed in the VFS. The fig.3.1 is showing the fabricated vertical farming structure with specification.

The structure has a triangular cross section having base width 132 cm and height of 167 cm. The height of the structure was fixed by considering the maximum possible reach of an average height person to harvest the crop. The VFS had two slanting faces of rectangular cross section having dimensions 183 cm x 180 cm each. The platforms were constructed across the slanting face.

Each platform having a width of 20.5 cm was enough for 15 cm x 15 cm grow bags. The height of each platform was designed according to the height of the structure and width of platform so that height of the first, second and third platform from top to bottom are 51 cm, 48 cm and 45 cm respectively.

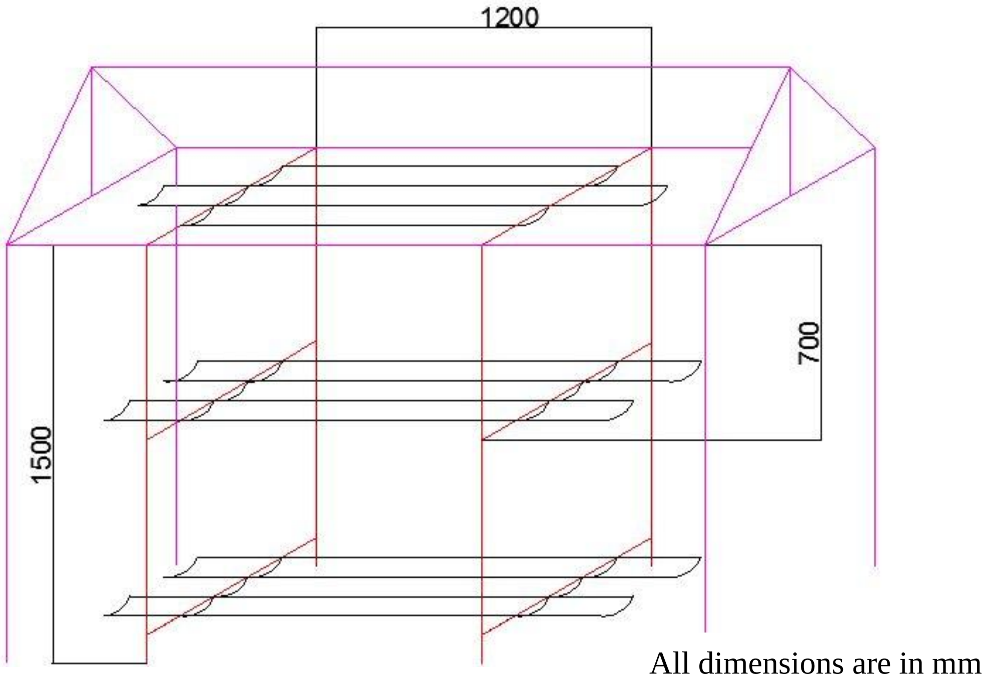


Fig.3.2. Modification of existing vertical farming structure

The roof has a quonset shape made up of MS rods of 1/2" diameter. The roof is supported by using MS rod of length 80cm at to the main structure at each corner. UV sheet of 200 micron of 230x180cm were used for covering the roof. Three rings were welded on the roof to place the PVC pipe for irrigation. The existing VFS is shown in fig.3.2.

Plate 3.1. Fabricated VFS **Plate 3.2. Existing VFS**

To compare the fabricated vertical farming structure (FVFS) with existing vertical farming structure (EVFS), the roof of the existing structure was covered by placing UV sheet of 200 micron of 150 cm x 200 cm over the structure. The existing VFS is shown in plate 3.2.

3.3 Installation of VFS

The north side of the LH KCAET was selected for the installation of fabricated VFS and the existing VFS. The structures were oriented in the east-west direction. 6 numbers of grow bags with 15 cm x 15 cm size were placed in each platform of fabricated VFS shown in plate 3.1. The total number of plants was 72. In existing VFS, 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 50 cm 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 coco peat and soil in the ratio 1:1.

3.4 Setup for Irrigation

The drip irrigation system was adopted to irrigate the plants. This was done to reduce the wastage of water during irrigation by supplying adequate quantity of water in the crop root zone. Main source of supply was water tank of LH, KCAET at a height of about 10 m from the ground level. The system worked under gravity. The supply was regulated by a ball valve. The discharge from the valve assembly was allowed to pass through a 3/4" PVC pipe to the main PVC pipe of 4" diameter held above the structure. The water was applied to the plants by using main lines and laterals. At the end of each line an end cap was provided for flushing the line. The emitters of 4 lph were installed for each crop. Irrigation in the existing structure was also done by drip irrigation method.

Plate 3.3. Drip irrigation system in FVFS and EVFS

3.5 Field Experiment

The different tiers of the fabricated and existing VFS were analyzed in this study. The details of the tier system which was used as the treatment is shown below:

FRT1- 1st tier at right side of fabricated structure from top

FRT2- 2nd tier at right side of fabricated structure from top

FRT3- 3rd tier at right side of fabricated structure from top

FLT1- 1st tier at left side of fabricated structure from top

FLT2- 2nd tier at left side of fabricated structure from top

FLT3- 3rd tier at left side of fabricated structure from top

ELT1- 1st tier at left section of existing structure from top

ELT2- 2nd tier at left section of existing structure from top

ELT3- 3rd tier at left section of existing structure from top

EMT1-1st tier at middle section of existing structure from top

EMT2- 2nd tier at middle section of existing structure from top

EMT3- 3rd tier at middle section of existing structure from top

ERT1- 1st tier at right section of existing structure from top

ERT2- 2nd tier at right structure of existing structure from top

ERT3- 3rd tier at right section of existing structure from top

3.6 Planting method

Selection criteria were based on characteristics such as height of plant, type of fruit, vitality and resistance to pests and diseases. Cowpea and amaranthus were selected for the study. Seeds of variety anaswara of cowpea were taken for the first trial and seeds were directly placed in the grow bags as well as in the half split PVC pipes. The amaranthus variety kannara local was taken for the second trial. The seedlings were transplanted in to the VFS. The depth of rooting media in the half split PVC was 9.5 cm and in grow bags was 10 cm. In the case of Cowpea, two seeds was placed in each grow bag of fabricated VFS. A total of 4 seeds were placed in each middle row and 2 seeds in side rows of the existing VFS. In the case of amaranthus, two seedlings per grow bag were transplanted in fabricated VFS and two seedlings each in middle and side rows of existing VFS.

3.7 Irrigation and Fertilizer application

Irrigation was given daily by drip irrigation method at a rate of 1.5 lit per plant. The fertilizer was applied at the rate of 3 to 5 g per plant in a single dose in both the VFS.

3.8 Observation of climatic parameters

Climatic parameters such as temperature and light intensity were observed for morning, afternoon and evening for a period of three weeks during the months of November, December and January after transplanting.

The daily observations were tabulated and the average values of observations of each week were noted and were used for plotting the graphs.

3.9 Biometric observations

For analyzing the growth pattern of the crops, crops from each tier were selected randomly from each side of fabricated and existing VFS. Biometric observations such as plant height, girth and number of leaves were made 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 fabricated and existing 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 fabricated and existing VFS.

3.10 Yield data

Harvesting of the second crop was done after attaining maturity. The first yield was taken one month after transplanting.

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The study has been undertaken with the objective of fabricating a VFS for homesteads, and to evaluate the performance of crops under fabricated VFS and to compare the performance of newly fabricated VFS with the existing one. Two trials were done for the study. The study was conducted from October 2015 to January 2016. For the first trial, cowpea (anaswara) was selected as the crop and the second trial amaranthus (kannara local) was selected. The climatological data and biometric observations were taken from the fabricated and existing VFS. The results of the study are discussed in this chapter.

4.1 Comparison of climatic data

Climatic parameters such as air temperature and light intensity were observed in the fabricated and existing VFS. The daily observations were noted at 8:00 am, 1:30 pm and 5:00 pm for a period of three weeks from November to December 2015 for the first trial with cowpea.

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 FVFS and EVFS are shown in fig.3. In the first week, temperature of FVFS and EVFS are same but for the second and third week there is a slight difference in temperature between the two VFS. The maximum temperature measured in FVFS was about 20.7ºC and in EVFS about 20.57ºC. Minimum temperature noted was 19.2ºC at FVFS and 19.1ºC at EVFS. There was only a small variation in air temperature in both the VFS at 8:00 am. The temperatures were almost the same in both structures.

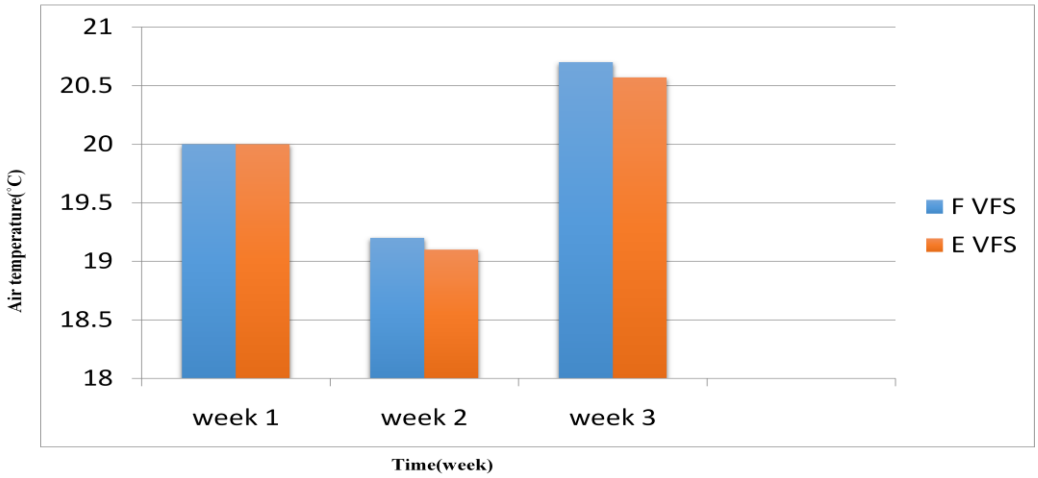


Fig.4.1. Variation of air temperature in FVFS and EVFS at 8:00 am.

Observations of air temperature at 8:00 am are shown in fig.4.1. A slight increase in air temperature inside FVFS was noted compared to EVFS during the noon hours. Observations of air temperature at 1:00 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 FVFS is 24.28˚C and in EVFS was 24.15˚C. Minimum temperatures were 24˚C and 23˚C respectively. This may be due to the more reflected radiation from the ground surface to the FVFS as there was a distance of 23 cm from the ground to the different tiers which was lesser in EVFS.

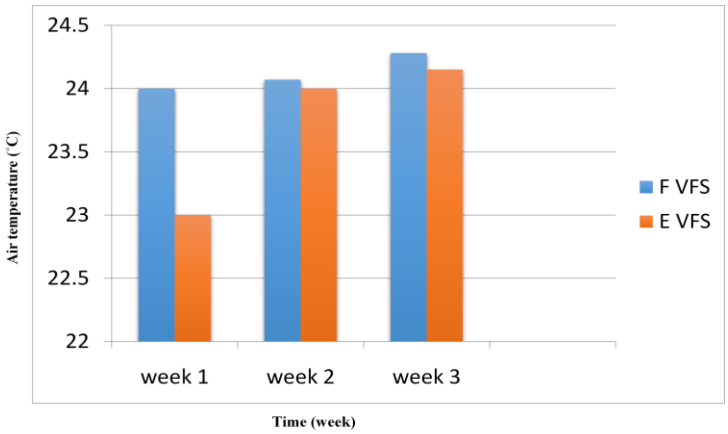


Fig.4.2. Variation of air temperature in FVFS and EVFS at 1:30 pm

The fig.4.3 showing air temperature of FVFS and EVFS at 5:00 pm describes that there was a small difference in temperature during the second week while it was almost the same in the first and third week. Maximum temperature in FVFS was about 22.93˚C and in EVFS was 22.8˚C. Minimum temperatures were the same for both structures i.e., 22.4˚C. The change in temperature was due to orientation of the structure.

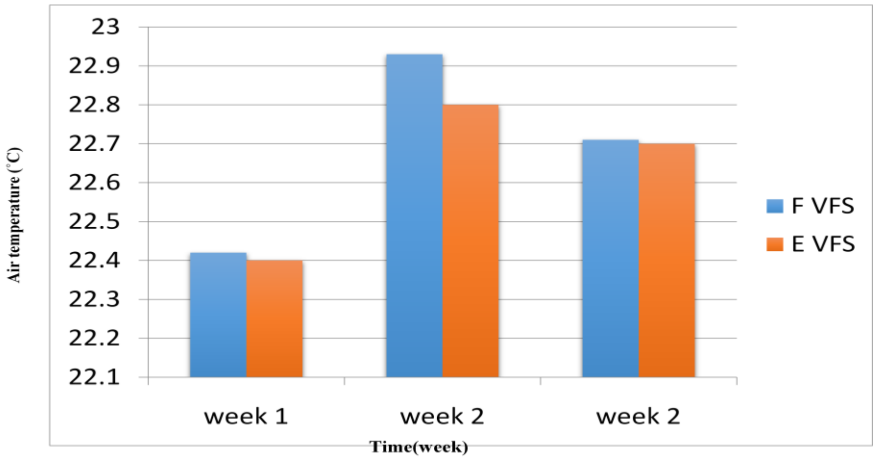


Fig.4.3. Variation of air temperature in fabricated VFS and existing VFS at 5:00 pm

The maximum temperature in a day was observed at 1:30 pm followed by 5:00 pm in both the VFS .The highest temperature was obtained in the third week and minimum in the second week.

4.1.2 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. Observations were obtained from the three tiers of left and right hand side of the FVFS. In EVFS, the measurements were taken from the three tiers of left, middle and right sections.

Fig.4.4 shows the variations in light intensity of FVFS at 8:00 am. The maximum light intensity was obtained from tier 3 (T3) at the right side of FVFS. It was about 6657.1 lux. The minimum light intensity of 3984.2 lux was measured from tier 2 (T2) on the left side of FVFS. The orientation of FVFS was east-west and availability of solar radiation in the morning hours, and reflected radiation obtained, maximum was observed in tier 3 which was close to the ground surface.

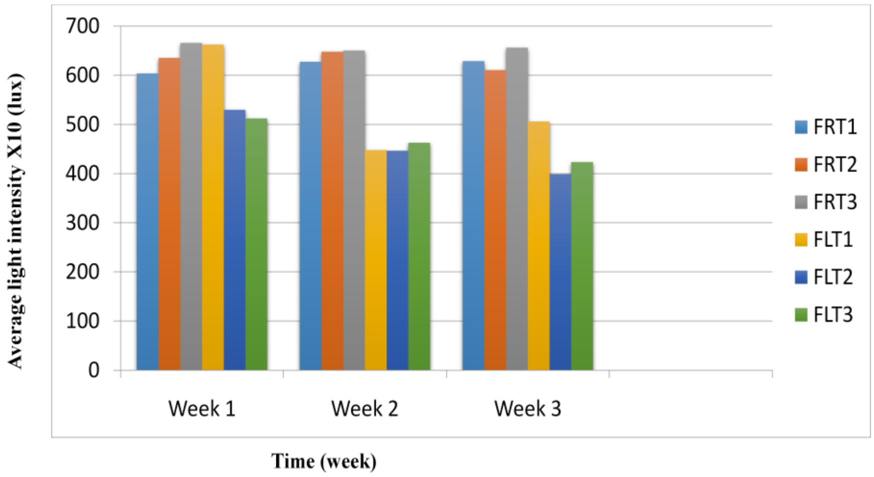


Fig.4.4. Variation in light intensity of FVFS at 8.00 am

Fig.4.5 shows the variation in light intensity of EVFS at 8:00 am. In EVFS, the maximum light intensity of 6580 lux was measured from the tier 2 (T2) at the left section and minimum of 2790 lux was measured from T3 at the middle section. Due to the orientation of the structure in east-west direction, in morning hours there was possibility of getting more solar radiation in left section of EVFS, which was towards the east.

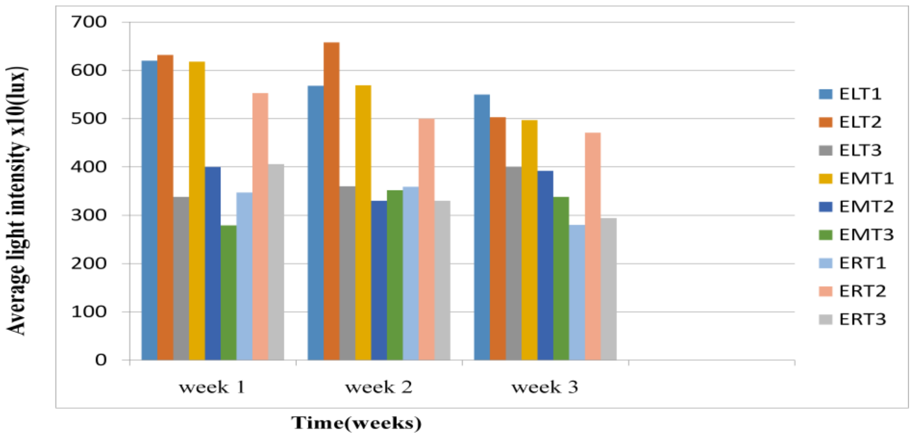


Fig.4.5. Variation in light intensity of EVFS at 8:00 am

Fig.4.6 and fig.4.7 shows the variations in light intensity of FVFS and EVFS respectively at 1:30 pm. The maximum light intensity was obtained from tier 1 (T1) at the right side of FVFS. It was about 12647 lux. The minimum light intensity of 5010 lux was measured from tier 2 (T2) on the left side of FVFS. The tier 1 is the uppermost one and is close to the roof than other tiers, direct transmission of light is possible compared other tiers.

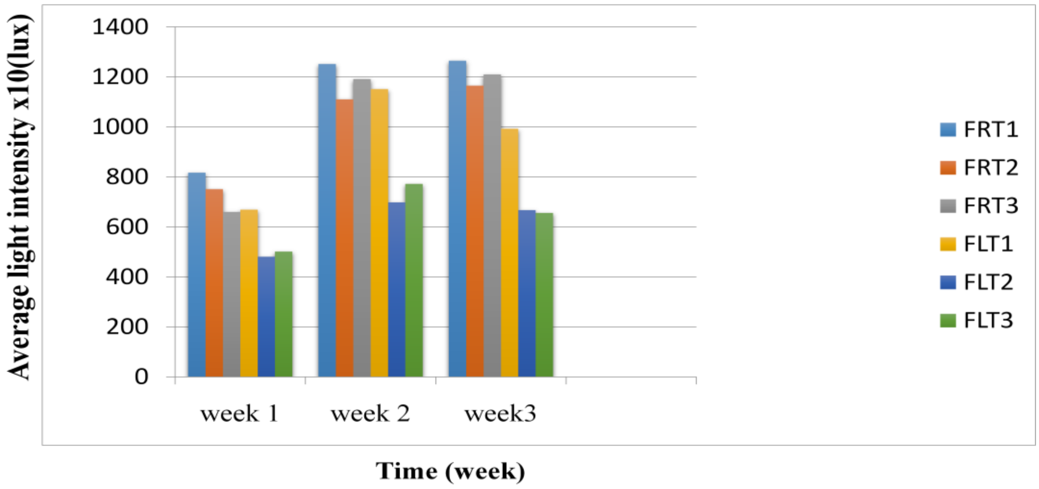


Fig.4.6. Variation in light intensity of FVFS at 1:30 pm

The tier 2 (T2) is the middle one, there may be chance of less light intensity compared to tier1 (T1) and tier 3 (T3) as there is less availability of direct sunlight and reflected radiations.

In EVFS, the maximum light intensity of 11200 lux was measured from the tier 1 (T1) at the middle section and minimum of 3470 lux was measured from T2 at the middle section.

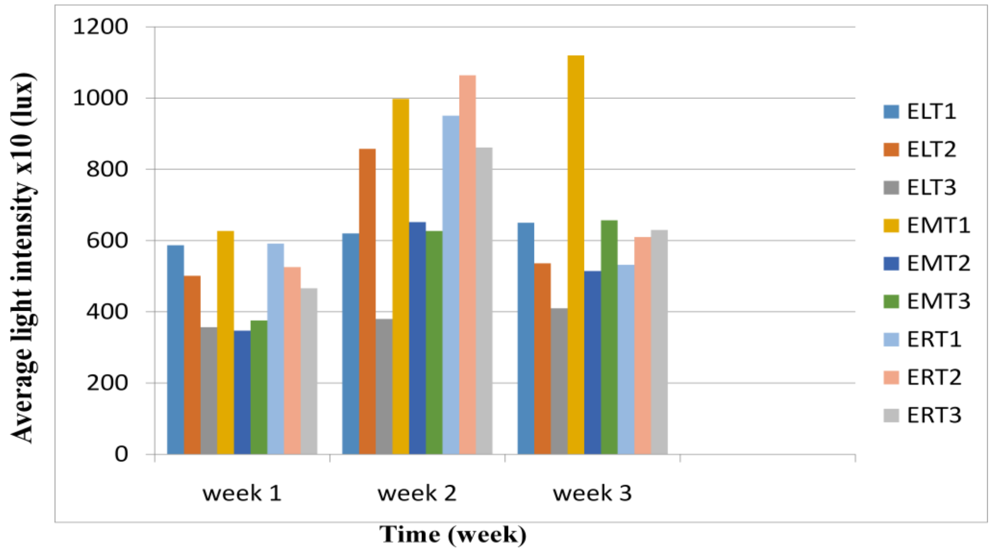


Fig.4.7. Variation in light intensity in EVFS at 1:30 pm

Fig.4.8 shows the variations in light intensity of FVFS at 5:00 pm. The maximum light intensity was obtained from tier 1 (T1) at the right side of FVFS. It was about 6674.2 lux. The minimum light intensity of 2150 lux was measured from tier 3 (T3) of left side of FVFS.

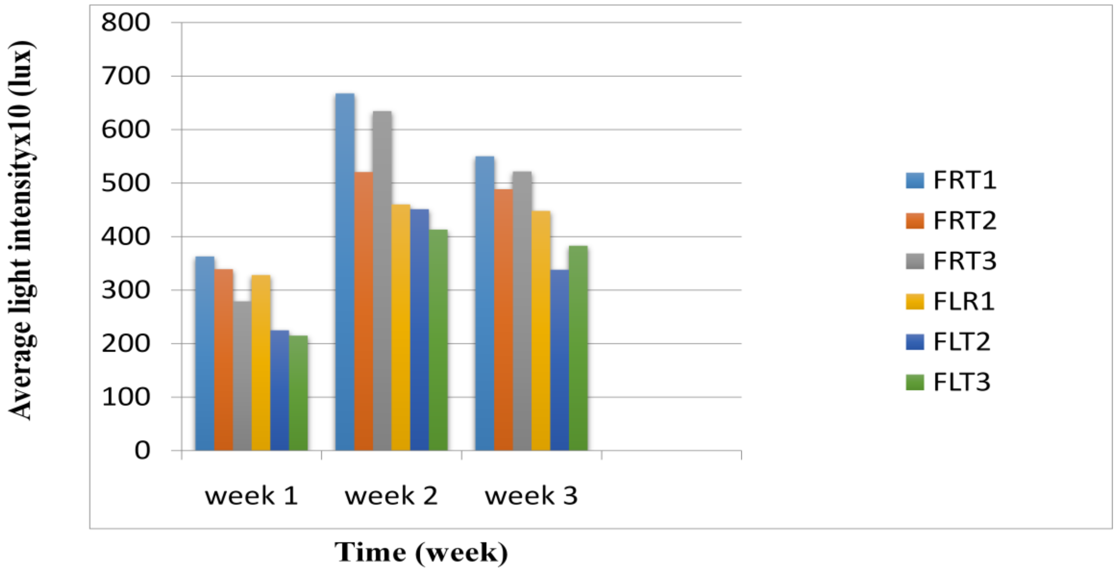


Fig.4.8. Variation of light intensity of FVFS at 5:00 pm

In EVFS, the maximum light intensity of 5386 lux was measured from the tier 1 (T1) at the middle section and minimum of 1781 lux was measured from T3 at the middle section (fig.4.9).

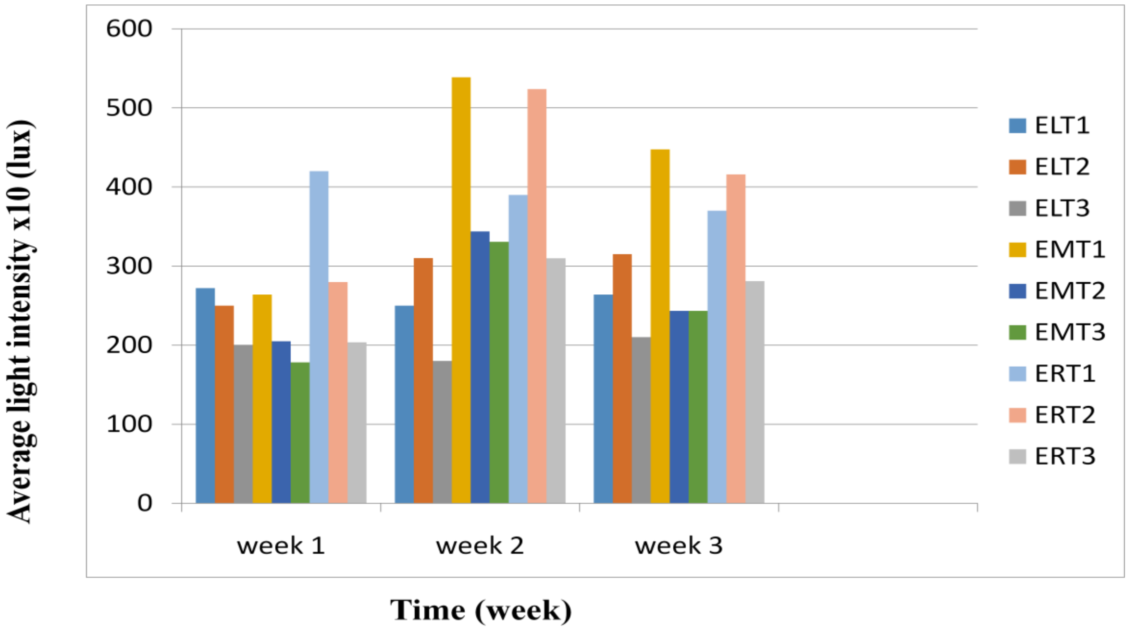


Fig.4.9. Variation in light intensity in EVFS at 5:00 pm

The maximum light intensity was observed at tier T1 on the right hand side of FVFS at 1:30 pm. From these observations, it was concluded that in the case of FVFS, at every time of the day, maximum light intensity was observed in tier 1 on the right hand side of the structure. This may be due to the east-west orientation and direction of reflected solar radiation. But in EVFS, maximum light intensity was observed in the left section in morning hours, middle section in afternoon and right section in evening hours. This may be due to the orientation of the structure.

4.2 Biometric observations for first trial (cowpea)

4.2.1 Plant Height

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

Maximum plant height at the end of 3rd week is observed at tier T1 on right side of FVFS and is about 68 cm. Minimum plant height of 12 cm was found at the tier T1 on the right section of EVFS. T1 on the left and right hand side of FVFS and left, middle and right sections of EVFS were taken and plotted in a graph as shown in fig.4.10. Similarly, T2 and T3 of each tier in both structures were also plotted as shown in fig4.11 and fig.4.12. The growth of plants was more in FVFS than in EVFS.

Considering tier T1 at the end of three weeks, the maximum plant height of 68 cm was at the right side of FVFS. Minimum plant height was found at the right section of EVFS and is about 12 cm. At tier T2, maximum plant height of 57 cm and minimum plant height of 34 cm were found at the right side of FVFS and left section of EVFS respectively. Similarly, at tier T3, maximum plant height of 62 cm and minimum plant height of 25 cm were found at right side of FVFS and left section of EVFS respectively.

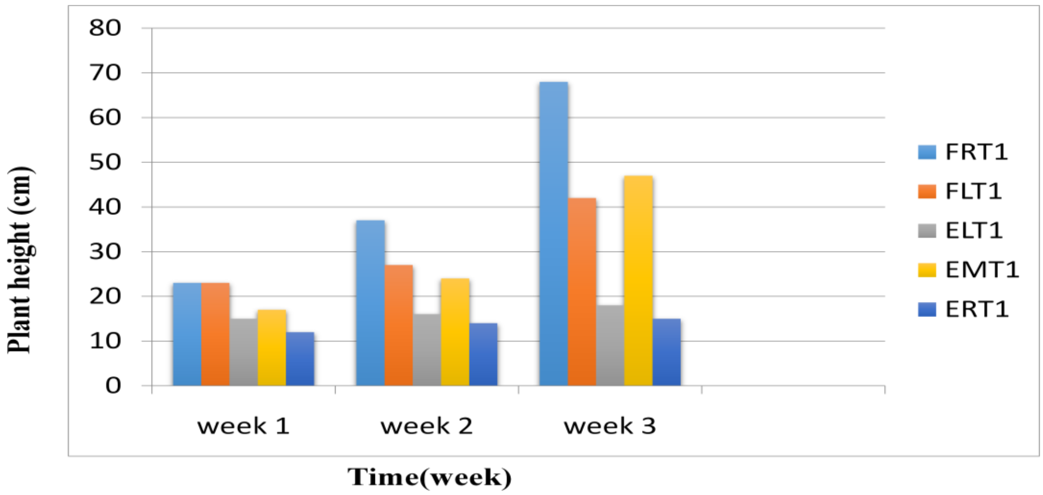


Fig.4.10. Variation of plant height in T1 of FVFS and EVFS

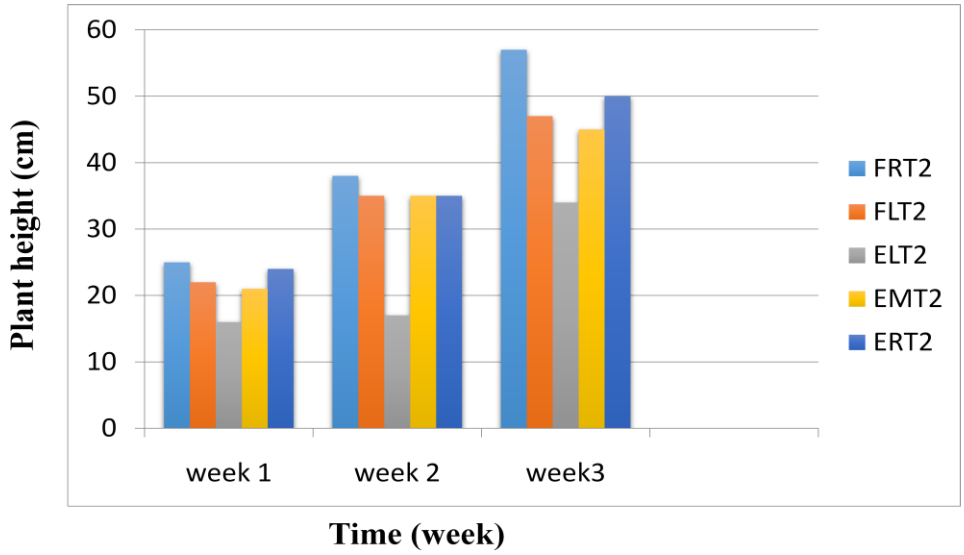


Fig.4.11. Variation of plant height in T2 FVFS and EVFS

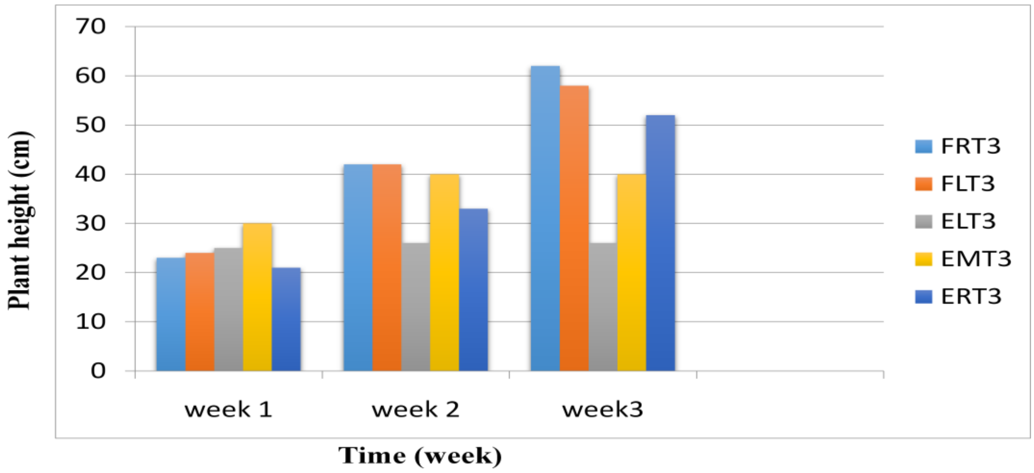


Fig.4.12. Variation of plant height in T3 of FVFS and EVFS

From the graphs, it is clear that plant height was observed to be maximum in the right side tier T1 followed by right side tier T3 in FVFS. This is correlated with the light intensity. The maximum light intensity was observed in these tiers. This may be the reason for the increase in plant height. In EVFS, the maximum plant height was observed at tier T3 of right section.

4.2.2 Number of leaves

At the end of 3rd week, the maximum number of leaves was found in the right side of FVFS and was 30 in number. Minimum number of leaves was found in the right section of EVFS was 4.

Considering T1 at the end of 3rd week, the maximum number of leaves was obtained at the right side of FVFS and minimum was obtained at the right section of EVFS and was found to be 17 and 4 respectively. At T2, 25 and 12 were the maximum and minimum number of leaves obtained from the right side of FVFS and left section of EVFS respectively. For T3, the maximum and minimum number of leaves was 30 and 5 and was found at the right side of FVFS and left section of EVFS. Variation in number of leaves with respect to time is shown in following figures (fig.4.13-4.15)

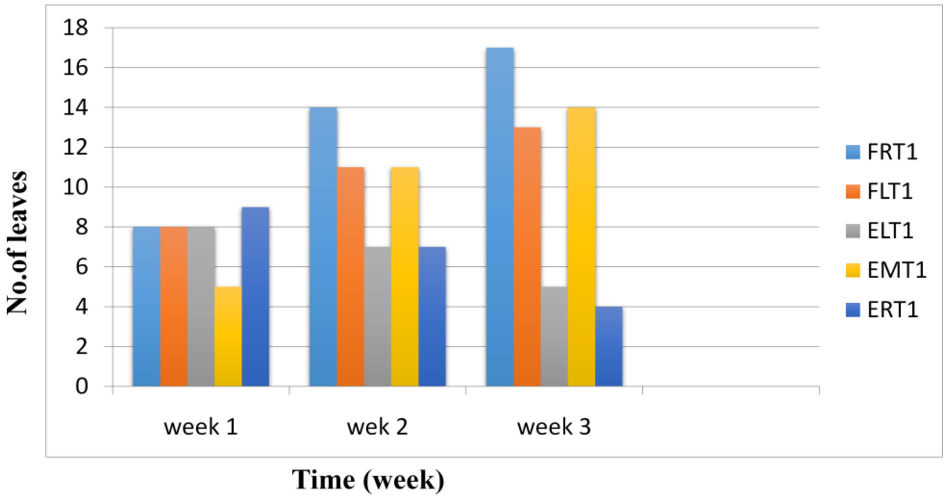


Fig.4.13. Variation of No. of leaves in T1 of FVFS and EVFS

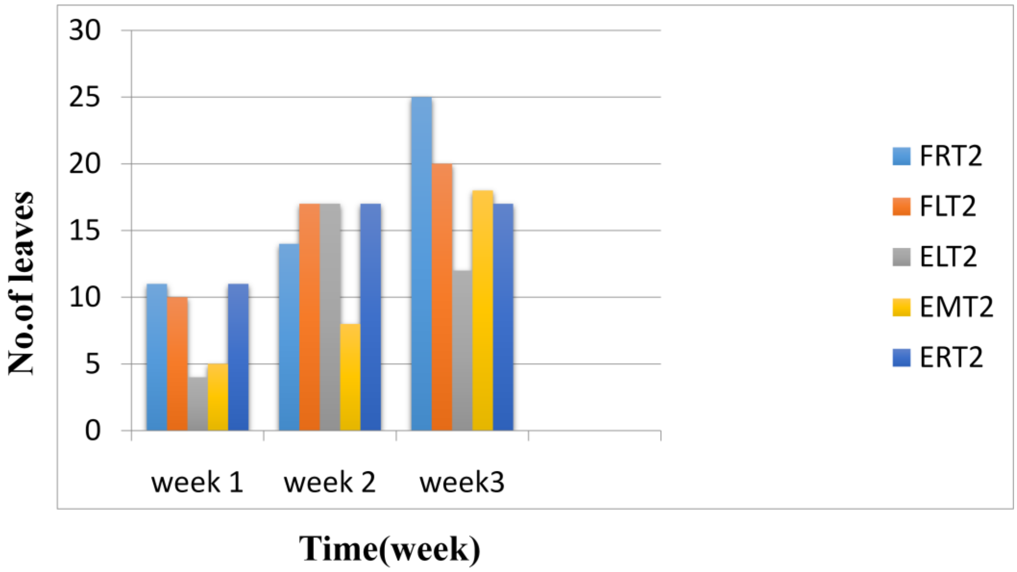


Fig.4.14. Variation of No. of leaves in T2 of FVFS and EVFS

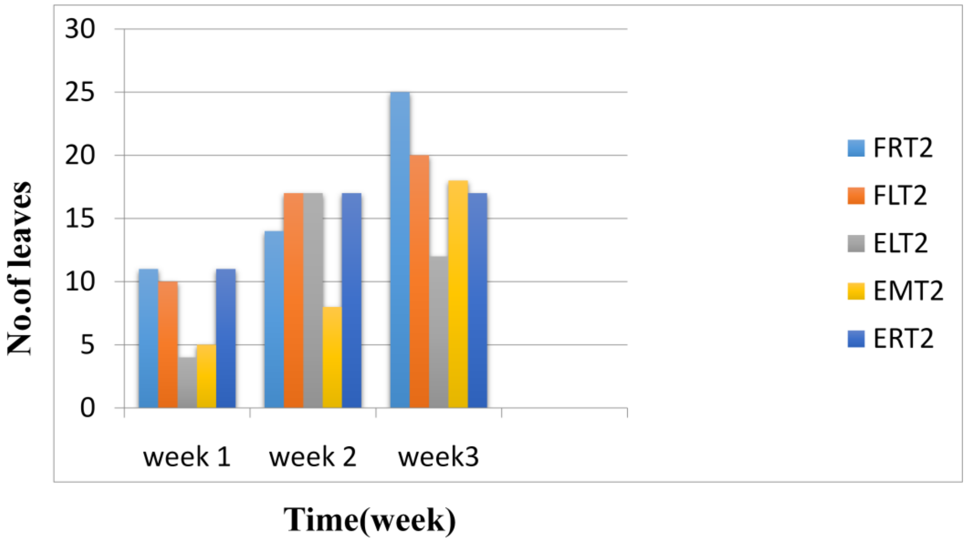


Fig.4.15. Variation of No. of leaves in T3 of FVFS and EVFS

From the fig.4.13-4.15, it is clear that number of leaves was observed to be maximum in the right side tier T3 followed by right side tier T1 in FVFS. This is correlated with the light intensity. The maximum light intensity was observed in these tiers. This may be the reason for the increase in number of leaves. In EVFS, the maximum number of leaves was found at tier T1 of middle section. More light intensity was observed in this part of the structure and hence more number of leaves.

4.2.3 Plant Girth

At the end of 3rd week the maximum plant girth was observed in the right side of FVFS and it was 1.7 cm and minimum was observed in the right and left section of EVFS and was about 0.9 cm.

Considering tier T1 at the end of 3rd week, maximum plant girth was obtained at the left side of FVFS and minimum from right section of EVFS and the recordings was 1.6 cm and 0.9 cm respectively. At tier T2 maximum and minimum plant girth were obtained at the right hand side of FVFS and left and middle sections of EVFS. The measurements were 1.7 cm and 1.4 cm respectively. Considering T3, maximum plant girth was of 1.6 cm at the right side of FVFS and minimum was about 0.9 cm at the left section of EVFS. Variation in plant girth with time is as shown in the fig.4.16-fig.4.18.

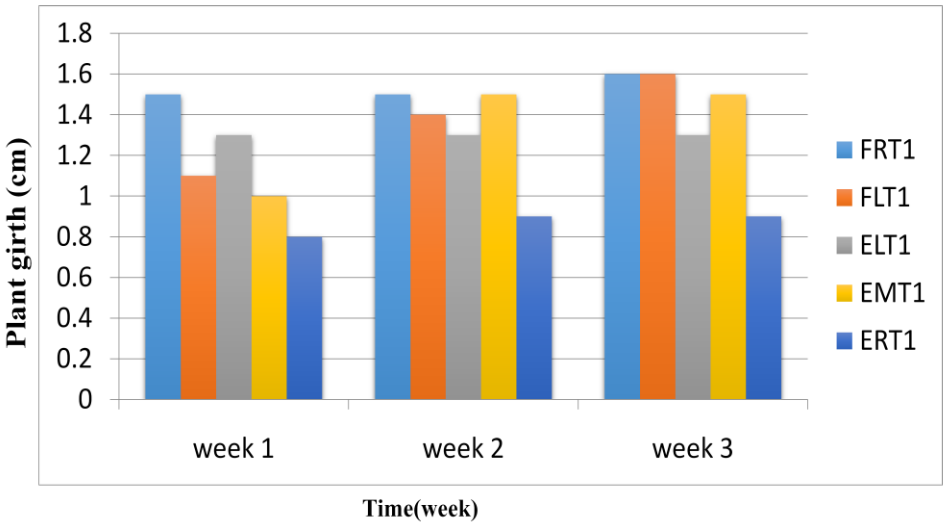


Fig.4.16. Variation of plant girth in T1 FVFS and EVFS

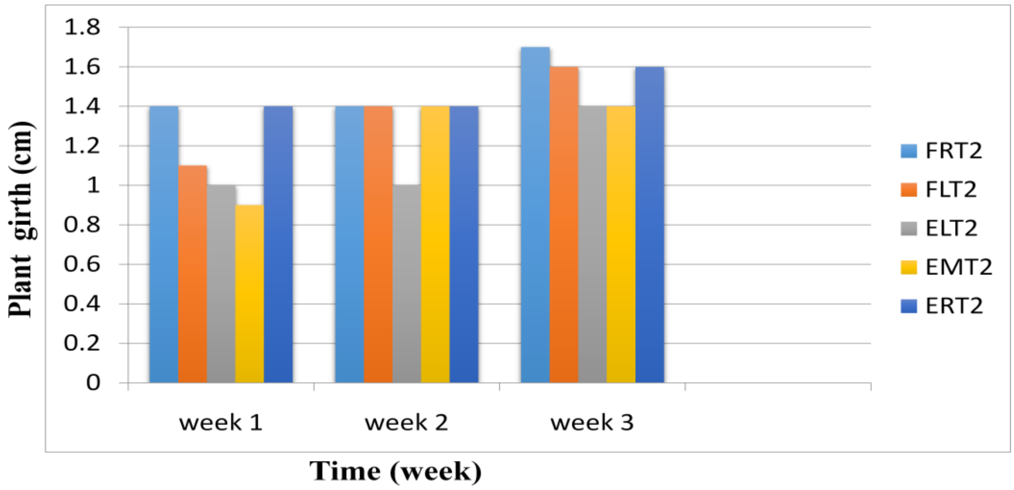


Fig.4.17. Variation of plant girth in T2 FVFS and EVFS

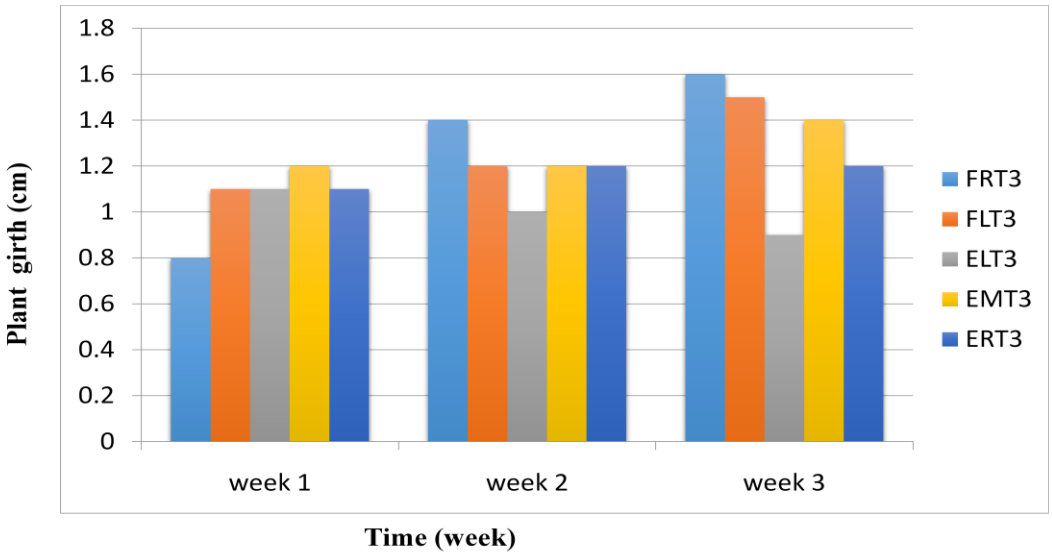


Fig.4.18. Variation of plant girth in T3 of FVFS and EVFS

From the fig.4.16-fig.4.18, it is clear that in the case of plant girth also, maximum girth for the plants was observed in right side of FVFS in different tiers. The maximum was observed in tier T2, i.e. on par with tier T1 and tier T3. The maximum light intensity was observed in these tiers. This may be the reason for the increase in plant girth. In EVFS, the maximum plant girth was observed at tier T2 of right section and tier T1 of middle section. The maximum light intensity was observed at middle and right sections.

4.3 Climatic data of trail 2 (Amaranthas)

4.3.1 Air temperature

The daily values of air temperature of both structures were taken. Variation of air temperature was almost similar in both structures like in cow pea. The maximum air temperature was measured in the 4th day at 1:30 pm and it was about 25.5˚C. The minimum temperature was observed in the 1st day at morning hours and it was about 19˚C.

Table 4.1. Daily measurements of Air temperature

Time	Day 1	Day 2	Day 3	Day 4	Day 5
8:00 am	**19**	19.5	19.5	20	20
1:30 pm	24.5	25	24	**25.5**	24.5
5:00 pm	22	22.5	23	24	22

4.3.2 Light Intensity

The variation in light intensity was same for amarantus and cowpea. The maximum light intensity was observed in T1 at right section of the fabricated VFS and minimum light intensity was obtained in T3 at middle section of the existing VFS. By considering the observations at 8:00 am, maximum light intensity was observed in T3 at right side of the FVFS and minimum was in T3 at middle section of the EVFS. At 1:30 pm, the maximum light intensity was in T1 at right side of the FVFS and minimum at the T2 of the middle section of the EVFS. At 5:00 pm the maximum and minimum light intensity were found in T1 at right side of FVFS and T3 at middle section of the EVFS.

4.4 Biometric data of trial 2 (amaranthus)

Table 4.2. Daily light intensity (lux)

Selected plant position	Day 1			Day 2			Day 3			Day 4			Day 5		
	8:00 am	1:30 pm	5:00 Pm	8:00 Am	1:30 Pm	5:00 Pm	8:oo Am	1:30 pm	5:00 Pm	8:00 Am	1:30 Pm	5:00 Pm	8:00 Am	1:30 pm	5:00 pm
FRT1	645	1605	362	414	1665	653	489	960	568	684	860	141	423	876	324
FRT2	674	1526	347	458	1488	614	476	934	544	665	830	125	451	774	306
FRT3	701	1509	279	489	1529	587	443	920	443	613	845	108	299	698	252
FLT1	574	1496	356	427	1396	632	456	764	534	597	715	117	312	801	272
FLT2	543	1007	297	401	1017	603	385	633	354	412	705	77	360	498	201
FLT3	529	1148	215	395	1348	498	413	500	467	398	650	60	392	431	169
ELT1	382	892	272	315	1327	484	435	788	435	540	485	127	388	759	276
ELT2	487	674	305	354	1247	535	366	672	346	464	464	78	418	669	191
ELT3	347	537	214	347	898	365	294	415	225	309	318	49	294	578	130
EMT1	374	915	320	412	1392	476	416	892	416	516	543	125	392	779	305
EMT2	320	575	224	375	880	398	316	674	314	301	387	62	256	334	167
EMT3	306	587	232	312	794	412	289	604	298	285	426	48	261	429	155
ERT1	364	938	273	384	1277	454	435	652	425	354	560	112	351	705	290
ERT2	355	1063	316	359	1472	478	560	758	560	503	532	106	240	775	309
ERT3	312	969	224	344	1017	313	469	753	466	290	456	53	182	594	181

Table 4.3. Biometric observations of amaranthus

SELECTED PLANT POSITION	READING 1			READING2		
	PLANT HEIGHT (cm)	NO.OF LEAVES	PLANT GIRTH (cm)	PLANT HEIGHT (cm)	NO. OF LEAVES	PLANT GIRTH (cm)
FRT1	9.3	5	0.7	49	51	3
FRT2	11	7	0.6	40	45	2.5
FRT3	10.5	8	0.6	48	48	2.8
FLT1	8.9	6	0.6	36	29	2.7
FLT2	7	5	0.5	27	16	2.3
FLT3	7.5	4	0.5	29	12	1.9
ELT1	6.5	4	0.6	16	24	1.2
ELT2	6.3	5	0.7	18	30	1.2
ELT3	6.8	4	0.6	8	7	0.8
EMT1	9	8	0.7	20	28	1.2
EMT2	9.1	6	0.5	12	14	0.8
EMT3	7.8	6	0.5	14	13	0.7
ERT1	6.9	5	0.5	16	10	1.1
ERT2	7.4	4	0.5	12	10	1
ERT3	7	4	0.5	10	8	0.8

Two sets of readings were taken for the biometric parameters after planting. It was found that the biometric parameters like plant height, number of leaves and plant girth were more in T1 at right side and followed by T3 at right side of FVFS. The plant characteristics are correlated with the sun light. This is the reason for more growth in right side of FVFS. The maximum plant height in FRT1and FRT3 is 49 cm and 48 cm respectively. The number of leaves in FRT1 and FRT3 were 51 and 48. The plant girth measured in FRT1 was about 3 cm and 2.5 cm in FRT3. In EVFS, the maximum plant growth was observed in T1 at middle section.

4.5 Yield data

The observation on yield for amaranthus was taken one month after planting. The plants in the FVFS had a better performance than EVFS. The total yield obtained in the FVFS was 545 g and in EVFS was about 125 g. The yield obtained from RT1 of FVFS was 165 g and 160 g in RT3 of FVFS. In EVFS the maximum yield was obtained in the T1 at middle section and it was about 45 g. The yield from FVFS was 63% greater than that from EVFS.

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

The study entitled the “Fabrication and performance evaluation of Vertical farming structure” was aimed at fabricating a vertical farming structure suited for homesteads and to compare the fabricated vertical farming structure with the existing vertical farming structure in the college.

The north side of the LH KCAET was selected to install both the fabricated and existing VFS .The two structures were located at the same area so that the temperature obtained was almost same. The number of crops accommodated in FVFS was 72 and in EVFS were 60.

Instead of planting in the half split PVC as in the existing VFS, metallic seating was provided in the fabricated VFS on which grow bags were placed. Grow bags of 15 cm x 15 cm were selected for planting the crops, so that 6 grow bags could be placed in the 183 cm x 20.5 cm sized platforms provided in the fabricated VFS.

To make the comparison efficient, slight modifications were done on the existing VFS by providing UV sheet same as that in the fabricated VFS. Drip irrigation was provided for both the structures with the water source being the tank of LH KCAET located 10 m above the ground level.

Cowpea of variety anaswara was selected for the first trial of the experiment and amaranthus of the variety kannara local for the second trial. In the first trial, seeds were placed in the grow bags and half split PVC pipes and in the second trial seedlings were transplanted into the VFSs. The grow bags and PVC splits were filled with coco peat and soil in the ratio 1:1. The fertilizer was applied at the rate of 3 to 5 g per plant in a single dose in both the VFS.

For the comparison of performance of each VFS, climatic parameters as well as biometric observations of crops such as plant height, plant girth and number of leaves were taken into account. Climatic parameters such as temperature, light intensity were measured in the morning, afternoon and in the evening at a fixed time for a period of three weeks. Biometric observations of randomly selected crops in each tier were taken once in a week at a fixed day for the same duration of period. The observations were tabulated separately for each structure and results were analyzed.

For the cowpea, the observations revealed that there are only slight variations in the temperature between the fabricated and existing VFS. The maximum temperature measured in FVFS was about 20.7 ºC and in EVFS about 20.57 ºC in the morning. Minimum temperature noted was 19.2ºC in FVFS and 19.1 ºC in EVFS. In the noon hours, the maximum temperature measured in FVFS was about 24.28 ºC and in EVFS about 24.15 ºC. Minimum temperature noted was 24 ºC in FVFS and 23 ºC in EVFS. In the evening, maximum temperature at FVFS was about 22.93 ˚C and at EVFS was 22.8˚C. Minimum temperatures were the same for both structures i.e., 22.4 ˚C. The slight variations in temperature may be due to the more reflected radiation from the ground surface to the FVFS as there is a distance of 23 cm from the ground to the lowermost tiers which was less in EVFS. The heat of respiration liberated by the crops also has a small role on this observed variation. Orientation of the structure reflects on the variation of the temperature among different tiers.

Depending on the time of measurement, the maximum and minimum light intensities obtained in each tier varied. In the morning, it was observed that FRT3 got the maximum light intensity and at the same time, minimum light intensity were observed on EMT3. This is due to the orientation of the structure in east-west direction. In morning hours there was possibility of getting more solar radiation in left section of EVFS, which was towards the east.

In the noon time, maximum and minimum light intensities were observed on FRT1 and EMT2 respectively. But in the evening maximum light intensity position was same as above. The minimum light intensity was observed at the same position as obtained in the morning. The observed changes may be due to the east-west orientation and direction of reflected solar radiation.

To compare the biometric observations for the trial with cowpea, the variations among crops on the same position were analyzed. Maximum plant height at the end of 3rd week was observed at tier T1 on right side of FVFS and was about 68 cm. Minimum plant height of 12 cm was found at the tire T1 of right section of EVFS. By considering all theT1 crops, the maximum plant height of 68 cm was at the right side of FVFS and minimum plant height was found at right section of EVFS which was about 12 cm. At tier T2, maximum plant height of 57 cm and minimum plant height of 34 cm were found at right side of FVFS and left section of EVFS respectively. Similarly, at tier T3, maximum plant height of 62cm and minimum plant height of 2 cm was observed at right side of FVFS and right section of EVFS respectively. Maximum plant height is observed at the tiers that receives maximum light intensity.

At the end of 3rd week, the maximum number of leaves was observed in right side of FVFS which was 30 in number. Minimum number of leaves was observed in left side of EVFS and it was 5 in number. The analysis revealed that rate of increase in the number of leaves was more on the right side of the fabricated VFS followed by the left side of the same structure. More light intensity was observed in this part of the structure and hence more number of leaves. This is due to the orientation of the structure in east-west direction.

In the case of plant girth also, maximum girth for the plants was observed in right side of FVFS. The maximum was observed in T2, i.e. in par with tier 1 and tier 3. The maximum light intensity was observed in these tiers. This may be the reason for the increase in plant girth. In EVFS, the maximum plant girth was observed at tier T2 of right section and tier T1 of middle section. The maximum light intensity was observed at middle and right sections. This is due to the orientation of the structure in east-west direction. Climatic and biometric parameters are directly correlated with each other.

Variation of air temperature and light intensity for amaranthus was almost similar in both structures like in cowpea. The maximum light intensity was found in T1 at right section of the fabricated VFS and minimum light intensity was obtained in T3 at middle section of the existing VFS. By considering the 8:00 am observations, maximum light intensity was measured in T3 at right side of the FVFS and minimum was in T3 at middle section of the EVFS. At 1:30 pm, the maximum light intensity was in T1 at right side of the FVFS and minimum at the T2 of the middle section of the EVFS. At 5:00 pm the maximum and minimum light intensity were found in T1 at right side of FVFS and T3 at middle section of the EVFS.

The biometric observation was done for the trial 2 with amaranthus. It was found that the biometric parameters like plant height, number of leaves and plant girth were more in T1 at right side and followed by T3 at right side of FVFS. The plant characteristics were correlated with the sun light. This was the reason for more growth in right side of FVFS. The maximum plant height in FRT1and FRT3 was 49 cm and 48 cm respectively. The number of leaves in FRT1 and FRT3 are 51 and 48. The plant girth was measured in FRT1 was about 3 cm and 2.5 cm in FRT3. In EVFS, the maximum plant growth was observed in T1 at middle section.

In the case of yield from the amaranthus, fabricated vertical farming structure had better performance compared to the existing VFS. Under the fabricated vertical farming structure, FRT1 and FRT3 exhibited the highest yields. The maximum yield from FRT1 was observed to be about 165 g and that from the FRT3 was about 160 g. Under the existing VFS, maximum yield was observed on EMT1 and corresponding yield was about 45 g. The total yield from the fabricated VFS accounted for about 545 g. The total yield from the potted cultivation was about 125 g. The yield from FVFS was 63% greater than that from EVFS. These results are obtained when the structure is oriented in east-west direction. The observations may change with the orientation of the installed structure.

The analysis of trials revealed that fabricated vertical farming structure shows better performance in every aspect compared to the existing vertical farming structure. Platform like structure can be recommended over PVC splits. The structure can also be recommended for urban areas and as a substitute to the traditional farming practices. The structure can be adopted for limited land area conditions and for the soils having drought, salinity and toxicity problems.

For the problematic soil, the structure can be placed in the field itself and for the limited land areas it can be placed even in the balcony or rooftops of the building. The orientation of the VFS can be changed according to the climatic parameters.

Scope of the study

- The study can be extended by providing different rooting medias
- The study can be extended by adopting balconies or rooftops under different conditions
- Study can be extended by providing UV sheets on the sides of the structure in addition to the roof.

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APPENDICES

APPENDIX I

Variation of Air Temperature of FVFS and EVFS at 8:00 am during three week period

TIME (weeks)	IST WEEK	2nd WEEK	3rd WEEK
FVFS	20	19.2	20.7
EVFS	20	19.1	20.57

APPENDIX 1I

Variation of Air Temperature of FVFS and EVFS at 1:30 pm during three week period

TIME (weeks)	IST WEEK	2nd WEEK	3rd WEEK
FVFS	24	24.07	24.28
EVFS	23	24	24.15

APPENDIX III

Variation of Air Temperature of FVFS and EVFS at 5:00 pm during three week period

TIME (weeks)	IST WEEK	2nd WEEK	3rd WEEK
FVFS	22.42	22.93	22.71
EVFS	22.4	22.8	22.7

APPENDIX IV

Variation of Light Intensity at FVFS at 8:00 am during three week period

WEEK	1st WEEK		2nd WEEK		3rd WEEK	
	RVFS	LVFS	RVFS	LVFS	RVFS	LVFS
T1	603.6	662.4	627.28	477.7	628.7	505.85
T2	635.28	529.7	648	446.3	610.42	398.42
T3	665.71	512	650.1	462.7	656.14	423.42

APPENDIX V

Variation of Light Intensity at FVFS at 1:30 am during three week period

WEEK	1st WEEK		2nd WEEK		3rd WEEK	
	RVFS	LVFS	RVFS	LVFS	RVFS	LVFS
T1	817	699	1251.5	1151	1264.7	993
T2	751.28	481	1110.5	698	1165.42	667
T3	660	501	1192	772	1210	656

APPENDIX VI

Variation of Light Intensity at FVFS at 5:00 pm during three week period

WEEK	1st WEEK		2nd WEEK		3rd WEEK	
	RVFS	LVFS	RVFS	LVFS	RVFS	LVFS
T1	363	328	667.42	460	550.14	448
T2	339	225	520.4	451	488.42	338
T3	279	215	635	413	522	383

APPENDIX VII

Variation of Light Intensity at EVFS at 8:00 am during three week period

WEEK	1st WEEK			2nd WEEK			3rd WEEK		
	LVFS	MVFS	RVFS	LVFS	MVFS	RVFS	LVFS	MVFS	RVFS
T1	620	618	347	568	569	359	550	497	280
T2	632	400	553	658	330	500	503	392	471
T3	338	279	406	360	352	330	400	338	294

APPENDIX VIII

Variation of Light Intensity at EVFS at 1:30 pm during three week period

WEEK	1st WEEK			2nd WEEK			3rd WEEK		
	LVFS	MVFS	RVFS	LVFS	MVFS	RVFS	LVFS	MVFS	RVFS
T1	587	627	591.6	620	997.4	950.8	650	657.5	532
T2	501	347	525.6	857.6	652	1064	536	514.5	609.5
T3	357	375.5	466	380	626.8	861	410	1120	629.75

APPENDIX IX

Variation of Light Intensity at EVFS at 5:00 pm during three week period

WEEK	1st WEEK			2nd WEEK			3rd WEEK		
	LVFS	MVFS	RVFS	LVFS	MVFS	RVFS	LVFS	MVFS	RVFS
T1	272.17	264	420	250	538.6	390	264	447.6	370
T2	250	205	279.67	310	343.8	523.8	315	243.4	416
T3	200	178.17	204	180	330.6	310	210	243.4	281

APPENDIX X

Variation of plant height in T1 of FVFS and EVFS

WEEK	FR	FL	EL	EM	ER
1st	23	23	15	17	12
2nd	37	27	16	24	14
3rd	68	42	18	47	15

APPENDIX XI

Variation of plant height in T2 of FVFS and EVFS

WEEK	FR	FL	EL	EM	ER
1st	25	22	16	21	24
2nd	38	35	17	35	35
3rd	57	47	34	45	50

APPENDIX XII

Variation of plant height in T3 of FVFS and EVFS

WEEK	FR	FL	EL	EM	ER
1st	23	24	25	30	21
2nd	42	42	26	40	33
3rd	62	58	26	40	52

APPENDIX XIII

Variation of no. of leaves in T1 of FVFS and EVFS

WEEK	FR	FL	EL	EM	ER
1st	8	8	8	5	9
2nd	14	11	7	11	7
3rd	17	13	5	14	4

APPENDIX XIV

Variation of No. of Leaves in T2 of FVFS and EVFS

WEEK	FR	FL	EL	EM	ER
1st	11	10	4	5	11
2nd	14	17	17	8	17
3rd	25	20	12	18	17

APPENDIX XV

Variation of No. of Leaves in T3 of FVFS and EVFS

WEEK	FR	FL	EL	EM	ER
1st	11	9	8	11	11
2nd	15	15	6	16	11
3rd	30	18	5	13	14

APPENDIX XVI

Variation of Girth in T1 of FVFS and EVFS

WEEK	FR	FL	EL	EM	ER
1st	1.5	1.1	1.3	1	0.8
2nd	1.5	1.4	1.3	1.5	0.9
3rd	1.6	1.6	1.3	1.5	0.9

APPENDIX XVII

Variation of Girth in T2 of FVFS and EVFS

WEEK	FR	FL	EL	EM	ER
1st	1.4	1.1	1	0.9	1.4
2nd	1.4	1.4	1	1.4	1.4
3rd	1.7	1.6	1.4	1.4	1.6

APPENDIX XVIII

Variation of girth in T3 of FVFS and EVFS

WEEK	FR	FL	EL	EM	ER
1st	0.8	1.1	1.1	1.2	1.1
2nd	1.4	1.2	1	1.2	1.2
3rd	1.6	1.5	0.9	1.4	1.2

DEVELOPMENT AND EVALUATION OF A VERTICAL FARMING STRUCTURE

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ABSTRACT

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ABSTRACT

The study entitled "Development and evaluation of a vertical farming structure" was taken up to fabricate a vertical farming structure and to compare the crops under fabricated vertical farming structure and existing vertical farming structure. For comparing the performance of plants under newly fabricated vertical farming structure and existing vertical farming structure climatic parameters as well as biometric observations were made. The analysis of these data suggested that adoption of newly fabricated VFS is advantageous than the existing one. The plant height, number of leaves, plant girth and yield varied between the two structures. The analysis of various data showed 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. The study suggested that newly fabricated VFS can be recommended more precisely as a substitute to the conventional farming practice on limited land area.