DEVELOPMENT AND PERFORMANCE EVALUATION OF AN AFFORDABLE HYDROPONIC STRUCTURE

By

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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PROJECT REPORT

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR-679 573, MALAPPURAM

KERALA, INDIA

2024

DECLARATION

We hereby declare that this project entitled "DEVELOPMENT AND PERFORMANCE EVALUATION OF AN AFFORDABLE HYDROPONIC 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 another university or society.

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CERTIFICATE

Certified that the project entitled **“DEVELOPMENT AND PERFORMANCE EVALUATION OF AN AFFORDABLE HYDROPONIC STRUCTURE”** is record of project work done jointly by **Aliya Omer Qasim K K, Deepak P, Mirfa Hanan Thadathil** and **Raj Laxmi** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

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DEDICATED TO OUR PROFESSION

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SYMBOLS AND ABBREVIATIONS

'	Minute
″	Inch
º	Degree
°C	Degree Celsius
%	Percentage
µS.cm^{-1}	Micro Siemens per centimeter
µmol m^{-2} s^{-1}	Micromol per square meter and second
dS.m^{-1}	Deci Siemens per metre
mS/cm	Milli Siemens per centimeter
q/ha	Quintal per hectare
lx	lux
Viz.	Videre licet
cm	Centimeter
g	Gram
N	Normality
mm	Millimeter
nm	Nanometer
EC	Electrical Conductivity
et al.	And Others
etc.	Et cetera
Fig.	Figure
i.e.	That is
m	Meter
W	Watt
m^2	Square Meter
ml	Millilitre
PPM or ppm	Parts Per Million
ppt	Parts Per Thousand
TDS	Total Dissolved Solids

KCAET	Kelappaji College of Agricultural Engineering and Technology
PVC	Poly Vinyl Chloride
RH	Relative Humidity
IBEF	Indian Brand Equity Foundation
GDP	Gross Domestic Product
NASA	National Aeronautics and Space Administration
NFT	Nutrient Film Technique
CEA	Controlled Environment Agriculture
NP	Nondeterministic Polynomial time
DWC	Deep Water Culture
LED	Light Emitting Diode
NDLI	Normalized Daily Light Integral
DC	Direct Current
AC	Alternating Current
KSEB	Kerala State Electricity Board
KVK	Krishi Vigyan Kendra
PAR	Photosynthetically Active Radiation
AM	Ante Meridiem
PM	Post Meridiem

Introduction

CHAPTER I

INTRODUCTION

In India, agriculture is the primary source of livelihood for about 58 percent of the population and approximately 70 percent of the rural households depend on agriculture only, with 82 percent of farmers being small and marginal (IBEF, 2021). As per Indian Brand Equity Foundation (IBEF), Ministry of Commerce and Industry, agricultural land in India is about 157.35 million hectares which is next to the United States. Around 60.3 percent of land in India is agricultural land (World Bank Data). The work force involved in agriculture and allied sector in India is about 50 percent of the total work force. India is the second largest country in farm output in the world, the seventh largest agricultural exporter in the world and the sixth largest net exporter (Balaganesh *et al.*, 2017). But the economic contribution of agriculture to India's Gross Domestic Product (GDP) is gradually declining since independence.

Agriculture and allied sectors in India accounted to only 22 per cent of the GDP in the year of 2022. Agricultural land holding is declining day by day because of many factors like increase in population, urbanization, bifurcation of agricultural lands, real estates, climate change etc. It is predicted that the world population will reach 9 billion by 2050, of which 70 per cent will live in urban centres. Many problems that the Indian agriculture sector is presently facing can be effectively resolved by vertical farming.

Growing crops vertically in stacks is known as vertical farming. Growing vertically allows for conservation of space, resulting in a higher crop yield per unit area of land used. Vertical farms are mainly located indoors, such as a warehouse, where they have the ability to control the environmental conditions for plants to grow. Vertical farming is a novel method of growing food that combines indoor farming, urban agriculture, and controlled agricultural environments. The aim of vertical farming is to increase the amount of agricultural land by ‘building upwards’ (Rishita *et al.*, 2022).

The idea of vertical farming was developed by Dickson Despommier, a Professor of Public and Environmental health at Columbia University. Despommier suggested growing plants vertically on different levels indoors. The idea for a 30 story vertical farm that could produce enough food for 50,000 people was then put out by Despommier and his students. This farm would have artificial lighting, advanced hydroponics and aeroponics. They also stated that about 100 varieties of fruits and vegetables could be grown on the upper floors, while chickens and fish would live on the plant waste on the lower floors. The concept of vertical farming has served as an inspiration for numerous subsequent designs. In 2017, the farm/school tower design won an award from the design publication eVolo (Rishita *et al*., 2022).

Vertical farming encompasses three prominent methods: hydroponics, aquaponics, and aeroponics. To grow food without soil, hydroponics uses mineral nutrient solutions. Hydroponics is defined in the Encyclopaedia Britannica as “the cultivation of plants in nutrient-enriched water, with or without the mechanical support of an inert medium such as sand or gravel”. The Greek words “hydro” and “ponos”, which mean "water working" or "water doing labour", are the origin of the term. Hydroponics has been identified by NASA researchers as a viable option for growing food in outer space. Onions, lettuce, and radishes are just a few of the vegetables they've had success growing. Overall, researchers have improved the hydroponic technique by attempting to make it more effective, reliable, as well as productive. Crop production in the absence of soil provides excellent environmental, growth, as well as development control. Hydroponics is now widely used in industrial agriculture because of its many advantages over soil-based cultivation. Hydroponics is a less labour-intensive method for managing large production areas. Additionally, it may be a more environment friendly process. When nutrients are evenly distributed to all plants, hydroponics can produce more consistent and higher yields than other methods (Salim *et al*., 2022).

Nutrient solution as well as supporting media can be recycled and re-used in hydroponic systems, allowing for customisation and modification. Some of the most frequently used systems are wick, ebb-flow, drip, deep water culture, and nutrient film technique. The ebb and flow (flood and drain culture) systems work by temporarily flooding the grow tray with nutrient solution and then draining the solution back into the reservoir by operating a pump. This is first commercial hydroponic system which works on the principle of flood and drain. Nutrient solution and water from reservoir flooded through a water pump to grow bed until it reaches a certain level and stay there for certain period of time so that it provides nutrients and moisture to plants. Besides, it is possible to grow different kinds of crops, but the problem of root rot, algae and mould is very common therefore, some modified system with filtration unit is required. Growing media for this system is rocks, gravel or granular rockwool suitable for vine crops (Salim *et al*., 2022).

In Nutrient Film Technique (NFT) tubes or pipes are used to inject the nutrients into to the growing tray. They flow over the plant roots and then drain away. In the 1960s, Dr. Alen Cooper came up with the NFT system to fix the problems with the ebb and flow system. In this system, water or a nutrient solution moves through the whole system and into the growth tray through a water pump that doesn't have a timer. The nutrient solution flows through the roots and returns to the reservoir via a system that is slightly slanted. Hydroponically grown plants have roots that dangle from a channel or tube. Many types of leafy greens, including lettuce, can be easily grown in this system, which is why it is so widely used in the commercial lettuce industry (Salim *et al*., 2022).

Different types of hydroponic systems based on structure are A-frame hydroponic system, U-shaped hydroponic system, vertical hydroponic tower, horizontal hydroponic system, inclined frame hydroponic system etc. All vertical structures are designed to maximize space utilisation and provide optimal growing condition for plants by allowing gravity to assist in nutrient distribution and water flow. The absence of weeds and pests lead to a better quality of products without hampering the taste or nutritional value (Hemlata *et al*., 2023).

Green vegetables are an important food source for the daily intake of essential nutrients. Recently various hydroponic experiments are conducted using spinach crop. *Spinacia oleracea Linn* is an important vegetable crop, which is widely produced due to short-duration production cycles and faster economic return. This crop is mainly a winter vegetable crop which survives low temperatures. The crop can how-ever, be successfully grown under partial shade in summer provided there is sufficient moisture at the root zone. So, it can be grown hydroponically in polyhouse (Nxawe *et al*., 2009).

Polyhouses are structures utilized as microclimate environment to make the plants grow well in unfavourable climate. They are extremely useful when plants, in particular period of the year, cannot be grown in open areas where the climate never guarantees a good quality crop. This has been evolved to create favourable micro-climates, which favours the crop production could be possible all through the year or part of the year as required (Dahiya *et al*., 2015). The various physical parameters such as moisture, humidity, available sunlight and temperature in the polyhouse are controlled. But these values can be easily altered using equipment's such as misters and foggers. The traditional method of farming is more prevalent in India, but now this new farming technology like polyhouse farming generates more income.

The objectives of this study are

1. To develop a simple vertical hydroponic system which can be used to grow leafy vegetables
2. To compare the developed structure with the existing NFT hydroponic system by evaluating the biometric parameters.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the review of previous research work carried out by many research workers, scientists and students. It comprises of review on vertical farming, vertical hydroponic technology, spinach cultivation in hydroponics, and evaluation of the spinach production system in terms of yield and water use efficiency.

2.1 VERTICAL FARMING

Rashmi and Pavitra (2018) described that vertical farming is the practice of growing crops in vertically stacked layers or integrated in other structures (such as in a skyscraper or old warehouse) with use of less water and no soil. The modern ideas of vertical farming use indoor farming techniques and Controlled Environment Agriculture (CEA) technology, where all environmental factors can be controlled such as artificial control of light, humidity, temperature, also bio fortification which is to breed crops to increase their nutritional value.

Hajer and Khalid (2020) proposed that vertical farming is crucial for sustainable cities due to various advantages. Urban agriculture has shifted from traditional to vertical farming solutions. Vertical farming addresses land shortage and enhances urban landscapes. Traditional agriculture faces challenges like pollution, high land prices, and food shortages. Vertical farming contributes to environmental sustainability and urban climate improvement.

Alberto *et al.* (2021) investigated the challenge of planning crop growth in vertical farming cabinets under controlled environmental conditions such as temperature, humidity, and light. The study aimed to meet the demand for crops by optimizing these conditions across various sections of the cabinets. The paper establishes the Nondeterministic Polynomial time (NP)-hardness of the problem and introduces an integer programming model that accounts for daily and shelf-specific changes in growth conditions over extended planning periods. The study also evaluated four objective functions, providing planners with flexible options based on their operational needs. A computational analysis using realistic datasets indicated that the chosen objective function significantly impacted the model's solvability and the quality of solutions obtained from standard solvers. This research contributed to the field by offering practical methods for optimizing crop production in vertical farming settings essential for sustainable agriculture and efficient resource utilization.

Blom *et al.* (2022) compared carbon footprints of vertical farming to conventional methods. The study focused on electricity use, carbon emissions, and sustainability of farming. The comparison included greenhouse gas emissions, energy sources, and crop yields. He evaluated carbon footprint of lettuce cultivation in various farming methods. An alternative scenario is explored to include the lost carbon sequestration potential by land-use change, identical packaging for all farming methods, and renewable energy usage. The carbon footprint of the vertical farm was 5.6 to 16.7 times greater than that of the conventional farming methods in the baseline scenario and 2.3 to 3.3 times in the alternative scenario. The electricity demands of the vertical farm represented 85% of the carbon footprint in the baseline scenario and 66% in the alternative scenario, suggesting that a significant reduction in electricity use is required to compete with conventional farming methods from a carbon footprint perspective. If this could be achieved, vertical farming could become a valid component of future sustainable and food secure systems by its efficient use of land, high yields, minimal use of water, nutrients and the ability to be located within or adjacent to cities.

2.2 VERTICAL HYDROPONIC SYSTEM

Matthew (2019) suggested a way to grow fresh food in cities by using the heating systems already in place. Since urbanisation is happening at a faster pace, it is important to grow food close to where people live. He proposed that vertical hydroponic farming could save water and space and reduce the distance food needs to travel. He recommended connecting these farming systems with heating systems, which could help save energy and reduce pollution. This combined method could make cities more secure in their food supply and help the environment too.

Salwa *et al.* (2022) conducted a study to look how to keep a hydroponic greenhouse at the right temperature for growing crops, like animal feed, without using soil. They use a system with pipes to control the temperature inside the greenhouse. They tested it in both hot and cold weather and found it worked well, making the plants grow better. They also found that this system is good for the environment and can help farmers produce more feed for animals.

Syed *et al.* (2023) addressed the need for energy-efficient hydroponic systems in closed plant production environments. This study compared the energy-use efficiency of two hydroponic systems, Nutrient Film Technique (NFT) and Deep-Water Culture (DWC). The study evaluated the impact of artificial lighting on crop growth dynamics, focusing on leafy green crops. Light Emitting Diode (LED) irradiation with specific parameters was utilized to ensure optimal growth conditions. Seedlings were grown in controlled environments before being transplanted into NFT or DWC systems. After five weeks of continuous LED irradiation, crop growth parameters were measured. Results indicate that the NFT system demonstrates higher energy use efficiency and better crop growth compared to the DWC system. This suggested that NFT systems offer superior energy savings and growth potential in plant factories and aquaponics facilities.

Wang *et al.* (2023) examined the effects of microbial inoculants on the growth and nutritional qualities of lettuce and celery in hydroponic systems. Specifically, two combined microbial inoculants were applied to promote plant growth and enhance nutritional values. After harvesting, various agronomic and physicochemical properties were evaluated. Results indicated significant improvements in plant growth parameters such as weight, root length, and leaf characteristics. Additionally, microbial inoculation led to enhanced root nutrient uptake and leaf photosynthesis, as evidenced by increased enzyme activity and chlorophyll content. Furthermore, the microbial treatment positively influenced the nutritional composition of both vegetables, including protein, vitamin C, phenols, anthocyanins, flavonoids, sugars, and dietary fibre.

Abdullah *et al*. (2023) conducted a study on how urban farming, particularly hydroponic farming without soil, can help provide food in cities where there is not much space for traditional farming. The study investigated the intention and adoption of hydroponic farming among urban Chinese residents, employing theories of planned behaviour and knowledge-attitude-behaviour. Through an online survey involving 661 respondents from various Chinese cities, factors influencing attitudes and intentions towards hydroponic farming were examined. It was found that people who were open to new ideas, knew about hydroponics, and thought it was important, were more likely to want to try it themselves. These findings contributed valuable insights to the development of effective farming frameworks, offering guidance for marketers, practitioners, and policymakers to promote modern agricultural practices and facilitate the adoption of urban hydroponic farming, particularly in developing countries. It showed that promoting hydroponic farming in cities could be a good way to make sure people have enough food and to protect the environment.

Cristina *et al*. (2024) explored how technology is changing the food industry to make it healthier and more sustainable. The study emphasized the potential of technological innovations, particularly in hydroponics and vertical farming, to mitigate food insecurity, enhance production efficiency, and transform supply chain dynamics. It discussed about how new technology can help produce food in a way that is better for the environment and for people's health. Through a case study of Nutritower, a Canadian hydroponic company, the authors delve into the intricate relationships between industry stakeholders and the societal implications of hydroponics and vertical farming. This work provides valuable insights into the multifaceted role of technology in addressing contemporary challenges in the food industry and lays the groundwork for further research in this area.

2.3 SPINACH CULTIVATION IN HYDROPONICS

Kadarkaraithangam *et al.* (2016) focused on understanding the impact of iron oxide nanoparticles on spinach plants grown through hydroponics, highlighting their potential implications for agricultural practices and environmental ecosystems. The study investigated the uptake of these nanoparticles by spinach and evaluated their effects on plant growth and productivity. Through experimental analyses, including plant growth measurements, biomass analysis, and magnetic property assessments, the study demonstrated a dose-dependent increase in plant growth and iron content due to nanoparticle uptake. Furthermore, the study discussed the mechanism of nanoparticle uptake using Fourier-transform infra-red spectroscopy. The findings suggested potential applications of iron oxide nanoparticles in agriculture, emphasizing the need for further research to explore their role in enhancing crop productivity and sustainability.

Lucas *et al*. (2020) aimed to assess the suitability of different cultivation systems for spinach plants irrigated with brackish water, focusing on water status and plant response to salinity. The study compared spinach growth in covered and uncovered soil and in a hydroponic floating system, using varying levels of brackish water salinity. Results demonstrated that the hydroponic system exhibited consistent growth with increasing salinity. Both covered soil and hydroponics showed better tolerance to salinity compared to uncovered soil. It recommended the use of plastic covers or hydroponic methods for spinach cultivation with brackish water, emphasizing their ability to mitigate the negative effects of salinity while maintaining plant growth and yield.

Yee Sin Go *et al*. (2023) investigated how well hydroponic farming can produce food compared to traditional soil-based farming. Data was gathered from different studies to see how much food different crops produced in hydroponic setups. Lettuce and chicory were the most studied crops. The study showed that spinach didn't do well in hydroponics compared to regular farming. It also looked at how factors like whether the plants were grown vertically or horizontally and if they were in a controlled environment affected crop yields. It was found that growing crops in controlled environments, like greenhouses resulted in higher yields.

Kaushal *et al*. (2023) discussed the potential of hydroponics, in enhancing crop efficiency and competitiveness. The study compared the growth patterns, yields, and nutritional quality of spinach and lettuce under different growing conditions, including greenhouse, room conditions, and open environment, using NFT hydroponic systems. Results indicated that spinach and lettuce grown in greenhouse NFT systems exhibited superior morphological characteristics, yield, and nutritional content compared to other conditions. Specifically, greenhouse cultivation showed higher plant height, leaf number, leaf area, fresh weight, and yield. Moreover, spinach and lettuce from greenhouse conditions displayed higher levels of sugars, pigments, and macro and micro-nutrients, making them healthier to eat. The study highlighted the potential of greenhouse NFT hydroponic systems in maximizing crop yield and nutritional quality while enhancing water and nutrient use efficiency to meet global food demands.

2.4 EFFECTS OF NUTRIENT SOLUTION PARAMETERS ON CROP GROWTH IN HYDROPONICS

Oztekin *et al*. (2018) examined spinach cultivation in a floating water culture system within a greenhouse in Izmir, Turkey. Different amounts of nutrients were used to see how it affected the plants. Results indicate that plant growth, yield, quality, and water consumption vary based on nutrient solution concentration and temperature. Lower nutrient solution concentrations resulted in higher vitamin C and leaf calcium content but lower leaf nitrogen, phosphorus, potassium, and iron content. The study suggests that spinach can be successfully cultivated as baby leaves in a floating water culture system, with a preference for half the normal nutrient application to reduce nitrate content while maintaining yield and water efficiency, particularly during the early spring season in greenhouse conditions.

Libia *et al*. (2012) considered 17 elements as essential for most plants, these are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, copper, zinc, manganese, molybdenum, boron, chlorine and nickel. With the exception of carbon and oxygen, which are supplied from the atmosphere, the essential elements are obtained from the growth medium. Other elements such as sodium, silicon, vanadium, selenium, cobalt, aluminum and iodine among others, are also considered beneficial because some of them can stimulate the growth or can compensate the toxic effects of other elements.

2.4.1 Temperature of nutrient solution

Nxawe *et al*. (2009) investigated the impact of different irrigation water temperatures on the growth of *Spinacia oleracea Linn* over an 8-week period in a greenhouse. Spinach seedlings were irrigated with water heated to varying temperatures (24°C, 26°C, and 28°C) using aquarium heaters connected to water tanks. Unheated tap water served as the control. All plants received a blend of Ocean HYDROGRO and Ocean HORTICAL nutrient solutions. Results showed that spinach grown with heated water exhibited greater leaf length, leaf number, and total fresh and dry weights compared to the control, with optimal growth observed at 28°C. These findings indicate that controlled spinach production in greenhouses during winter seasons is feasible through irrigation with heated water.

Nxawe *et al*. (2011) explored how the temperature of water can affect plant growth. When the water is too hot or too cold, it can change plants work inside. This includes things like how they absorb nutrients, make energy from sunlight, and even how they grow and develop. Getting the water temperature just right helps these processes work better, which means the plants can grow stronger and healthier. This study suggested that controlling the water temperature in hydroponic systems could be helpful for growing crops better during the winter months in greenhouses.

2.4.2 pH of nutrient solution

Wang *et al*. (2015) study aimed to find the best pH level for growing spinach in a hydroponic system. Four different pH levels of the nutrient solution were tested to see how it affected the growth and quality of the plants. It was found that if the pH wasn't controlled and went too high (pH 8.2), the spinach didn't grow well. But when nitric acid was added to adjust the pH to a reasonable level, the spinach grew better. Controlling pH helped the plants take in more nutrients and water, leading to taller plants with more leaves and heavier shoots. Although nitrate levels increased slightly, they were still safe. However, the vitamin C content decreased when pH was controlled at 6.5. Overall, keeping the pH around 7.0 gave the best results for both yield and quality of the water spinach.

Daniel *et al*. (2020) showed the impact of varying pH levels of nutrient solutions on the growth of basil plants in a hydroponic system. The researchers believed that adjusting certain nutrients could help the plants grow better at lower pH levels while also reducing the risk of a disease caused by a type of water mold. Different pH levels, from 4.0 to 5.5 was tested and response of basil plants was observed. It was found that adjusting the pH to 4.0 helped protect the plants from the disease without hurting their growth. This suggested that controlling pH levels cis important for growing healthy plants in hydroponic systems.

Daniel *et al*. (2021) delved into how different pH levels in the nutrient solution affected the growth of spinach in hydroponic systems. It aimed to find an optimal nutrient management strategy for growing spinach efficiently. By adjusting the pH of the nutrient solution from 4.0 to 5.5, significant changes were observed in the spinach plants growth. Lower pH levels, especially at 4.0, led to stunted growth and poor root development. Analysis of the plant's tissues revealed reduced levels of essential nutrients like nitrogen, phosphorus, and potassium as the pH decreased. Although increasing the strength of the nutrient solution at pH 4.5 somewhat improved growth, it didn't fully restore it to normal levels.

2.4.3 Electrical conductivity of nutrient solution

Daniel *et al*. (2021) investigated the influence of Electrical Conductivity (EC) of 'Corvair' spinach plants in hydroponic systems. Spinach growth was evaluated by monitoring EC levels. Increasing the strength of the nutrient solution at pH 4.5 improved shoot and root weight, yet it remained lower compared to control conditions (pH 5.5, EC 1.4 $dS.m^{-1}$). However, under conditions of low pH and increased EC (pH 4.5, EC 3.4 $dS.m^{-1}$), leaf nutrient concentrations were comparable or even higher than control, suggesting the potential of further optimization of nutrient formulas. These findings underscore the critical role of EC in nutrient uptake and growth, offering insights for enhancing hydroponic leafy greens production efficiently.

2.4.4 Total Dissolved Solids (TDS) of nutrient solution

Samika (2023) emphasized the significance of Total Dissolved Solids (TDS) concentration in hydroponic systems. The research investigated its effects on the growth, productivity, and nutrient composition of spinach (*Spinacia oleracea Linn*). Through the comparison of three TDS levels-low, moderate, and high-the study endeavoured to discern the optimal range for the growth and maximizing the yield of spinach in hydroponic setups. The study indicated that higher TDS levels in the nutrient solution enhanced nutrient uptake, leading to improved plant growth in hydroponic spinach. But there is an optimal range (1200 ppm) to avoid potential negative effects and diminishing returns. It was observed that plants exposed to elevated TDS levels exhibited larger and heavier spinach leaves, contributed to a higher overall biomass accumulation and increased yield. Beyond a certain threshold (approximately 1400 ppm), the growth rate tends to plateau, which indicated excessive high TDS levels does not provide additional growth benefits and could even lead to diminishing returns.

2.5 EFFECTS OF MICROCLIMATIC PARAMETERS ON CROP GROWTH

Martin (2016) investigated how spinach composition changes in response to daily light and temperature variations in a greenhouse. This study compared different light levels using a measure called Normalized Daily Light Integral (NDLI), which takes into account both light intensity and leaf area. Results showed that higher light levels led to increased dry mass compared to fresh mass. Nitrogen levels varied with time of day under high light but not low light. Temperature affected nitrate and amino acids more than light intensity. Starch levels increased with light intensity, while sugars decreased with temperature. Oxalic acid levels increased with both light intensity and temperature. Throughout the day, starch peaked in the evening, while sugars had high levels during the day and low levels at night. Oxalic acid increased towards the end of the day. These findings suggest that spinach growth might slow down in cooler temperatures, affecting its sugar and nitrate metabolism.

Sanjivani *et al*. (2018) conducted an experiment during the summer seasons of 2016-2017 at the Department of Farm Structures to design and evaluate a hydroponic structure for cultivating leafy vegetables. Different methods of hydroponics were used for growing spinach both indoors and outdoors. The portable hydroponic structure was constructed from locally available materials. Iron and chlorophyll content of spinach were assessed using distinct determination methods after crop maturation. Analysis via Design Expert version 9.0.2.0 with response surface methodology revealed a maximum moisture content of 90.877% and a peak leaf area of 32.798 dm/m^2. Spinach yield was highest within the green hydroponic structure (150-210 q/ha), followed by the white hydroponic structure (120-200 q/ha), and least in the open field (50-80 q/ha).

Kaushal *et al.* (2023) compared the growth patterns, yield, and nutritional quality of spinach and lettuce in different growing conditions, including greenhouse NFT hydroponic systems, room conditions, and open environments. Results showed that spinach grown in greenhouse NFT systems had superior growth and yield compared to other conditions, while lettuce thrived best in room conditions. Plants in the greenhouse NFT system exhibited higher levels of sugars and pigments, indicating better nutritional quality. Additionally, spinach and lettuce grown in the greenhouse had higher levels of both macro and micronutrients. The results suggested that greenhouse NFT hydroponic systems are optimal for maximizing yield and nutritional quality in spinach and lettuce cultivation.

Santosh *et al.* (2023) developed optimum microclimate control within polyhouses to enhance plant growth and yields while minimizing negative effects. It emphasized the significance of balancing various environmental factors, including temperature, ventilation, and carbon dioxide levels, to create an ideal growth environment for crops. It discussed the importance of avoiding excessive control, which may harm crop health, and encouraged optimal environmental control methods to achieve desired outcomes while reducing emissions and production costs. Furthermore, it highlighted the need to consider factors such as crop type, local climate, and available resources when implementing microclimate control strategies. By optimizing microclimate conditions, farmers can increase crop yields and enhance produce quality.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the materials used and methodologies adopted for the study entitled "Development and Performance Evaluation of an affordable hydroponic structure" conducted at Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, Kerala.

The comparison between the developed system and an existing NFT hydroponics system developed by Nandhini, M.Tech. student at KCAET was also done. The experiment aimed to develop affordable hydroponic structure for small houses. The comparison was based mainly on cost and yield.

3.1 DETAILS OF EXPERIMENTAL SETUP

3.1.1 Study area

The experiment was conducted in the naturally ventilated polyhouse (Plate 3.1) in the research plot of Department of Irrigation and Drainage Engineering situated near the ladies' hostel, KCAET, Tavanur. The site is situated at 10° 85' N latitude and 75° 98' E longitude with an altitude of 13 m above mean sea level.

Plate 3.1 Naturally ventilated polyhouse

3.1.2 Climate of the study area

The area receives both South West monsoon and North East monsoon and a few summer showers. South West monsoon contributes the major part of total rainfall. The average annual rainfall of the area is 2500 mm to 2900 mm. The maximum temperature ranges from 30°C to 40°C and the minimum temperature range from 25°C to 29°C. The maximum relative humidity of the area is 92.5% and the minimum relative humidity is 69.87%.

The environment inside the polyhouse was maintained by using exhaust fans and foggers (Plate 3.2).

(a) (b)

Plate 3.2 (a) Exhaust fan (b) Fogger

3.1.3 Components and construction of developed vertical hydroponics system

A tower structure consisting of a series of stacked buckets were designed and installed in the polyhouse to grow the crops in the study. The experimental design and construction of the hydroponic structure are shown in Fig. 3.1 and Plate 3.3 respectively.

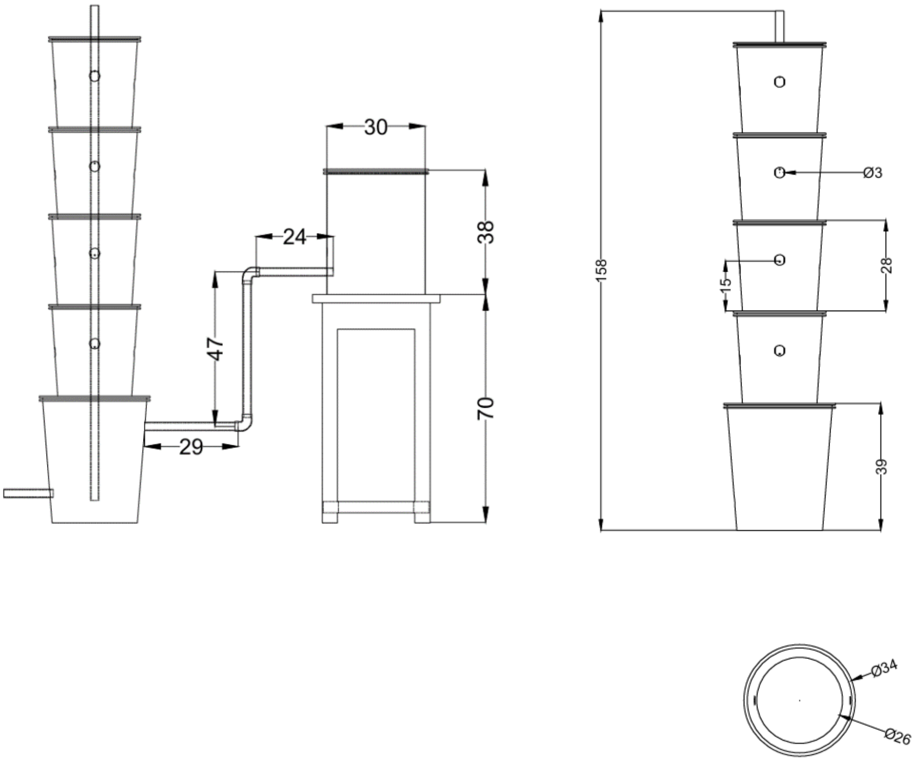


Fig. 3.1 Experimental design of hydroponic system

(All measurements are in cm)

Plate 3.3 Developed structure installed at the polyhouse

The developed vertical hydroponic structure consists of buckets, submersible pump, PVC pipes, float valve, sponge, stool and ball valve.

3.1.3.1. Buckets

Four buckets, each of 28 cm height is stacked in layers, with a nutrient mixing tank at a height of 70 cm from ground and a supply tank with a height of 39 cm at the base, completes the structure of tower. Supply tank and nutrient mixing tank of 20 L and all other buckets of 10 L capacity is used.

Holes (1.25″ diameter) are drilled in each stacked buckets at four sides at a height of 15 cm from bottom of buckets. Plants are kept in these holes. Holes (1.25″ diameter) are also drilled on lids and bucket base for recirculating nutrient solution as shown in Plate 3.4. Both nutrient mixing tank and supply tank was provided with insulation to protect from heat (Plate 3.5).

(a) (b)

Plate 3.4 Holes made in: (a) Bucket (b) Lid

Plate 3.5 Insulated bucket

Table 3.1 Measurements of buckets used

	No.	Height (cm)	Diameter (cm)	Capacity (Litre)
Stacked buckets	4	28	26	10
Supply tank	1	39	34	20
Nutrient mixing tank	1	38	30	20

3.1.3.2. Submersible pump

A submersible pump (Plate 3.6) of 60 W was used to pump nutrient solution from the supply tank to a height of 2m in this study. The size of the pump is decided based on the total head against which the pump is to be worked. The head against which the pump is to be worked is the distance from the water level in the nutrient solution tank to the highest level to which the water is to be lifted.

Plate 3.6 Submersible pump

3.1.3.3. PVC pipes

PVC pipes of 158 cm is fitted to the pump through the centre of stacked buckets for the circulation of nutrient solution from supply tank to plants. Holes at four sides are drilled with an interval of 28 cm for making nutrient solution available to respective plants at four sides of the buckets. It is also used for connecting supply tank to the nutrient mixing tank.

3.1.3.4. Float valve

A float valve (Plate 3.7) is installed inside the supply tank to maintain the water level in it, as shown in Plate 3.8. It operates on a simple principle: the float rests on the surface of the water and moves up and down with the water level. When the water level drops, the float triggers a valve to open, allowing water to flow in until the desired level is reached. Similarly, when the water level rises, the float rises too and eventually shuts off the valve to stop the inflow of water. This helps to prevent damage of submersible pump due to lack of water.

Plate 3.7 Float valve

Plate 3.8 Float valve installed inside supply tank

3.1.3.5. Ball valve

It is fitted at the bottom of the supply tank and at the end of vertical PVC pipe, as shown in Plate 3.9 and Plate 3.10. In supply tank, it is used for taking samples to analyse nutrient solution parameters. Whereas, at the end of PVC pipe, it is used for adjusting pressure so that water reaches the plants.

Plate 3.9 Ball valve fitted at the end of vertical PVC

Plate 3.10 Ball valve fitted at the bottom of supply tank

3.1.3.6. Sponge

Cotton mix sponges of 8.5×6 cm (Plate 3.11) are kept on bucket after rolling plants inside them. It is used for holding the plants and for absorbing nutrient solution.

Plate 3.11 Sponge

3.1.3.7. Power supply

Both the structures are powered by a solar energy system. Four solar panels (Plate 3.12) are installed outside the polyhouse, capturing sunlight and converting it into electricity through photovoltaic cells. The generated electricity is then converted from Direct Current (DC) to Alternating Current (AC) using inverters. Additionally, the system includes battery storage to retain excess energy for use during night time or cloudy days, ensuring a consistent power supply. When there was battery shortage, Kerala State Electricity Board (KSEB) was used as an alternative.

Plate 3.12 Solar panel

3.1.4 Spinach

The test crop selected for the study was Spinach, which is a leafy vegetable and very economic. Scientifically it is known as *Spinacia oleracea Linn*. It is an edible flowering plant in the family of Chenopodiaceae, common name is spinach or in Hindi known as ‘Paalak’. It is an annual plant, which grows to a height of up to 30 cm. Spinach may survive over winter in temperate regions. Though Spinach is most often used as a food, it has medicinal value as well. Spinach is packed with vitamins such as vitamin C, vitamin A and vitamin E and minerals like magnesium, manganese, iron, calcium and folic acid. Spinach is also a good source of chlorophyll, which is known to aid in digestion. Spinach is also rich in the carotenoids, beta-carotene and lutein. Spinach is known to be a healthy product and contains relatively high concentrations of bioactive compounds and general crop characteristics are given in Table 3.2 (Namrata *et al*., 2015).

Table 3.2 Characteristics of spinach

No. of leaves	10-20
Leaf length	6-10 cm
Leaf width	4-6 cm
Plant height	20-30 cm

Table 3.3 Growth requirement for spinach (Nisha *et al*., 2018)

pH	5.5-6.5
EC	1.8-2.3 dSm^{-1}
TDS	200-450 ppm

3.1.5 Nutrient solution

A nutrient solution for hydroponic systems is an aqueous solution containing mainly inorganics ions from soluble salts of essential elements for higher plants (Libia and Fernando, 2012). Plants require a total of sixteen chemical elements for growth and production: Carbon, Nitrogen, Phosphorus, Potassium *etc*. (Malavolta, 2006). Nutrients are divided into two groups – micronutrients and macronutrients (Table 3.4).

Table 3.4 Different types of nutrients

SI. No.	**Macronutrients**		**Micronutrients**
	Primary nutrients	**Secondary nutrients**	
1.	Nitrogen	Magnesium	Zinc, Manganese, Iron,
2.	Potassium	Calcium	Boron, Chlorine, Copper
3.	Phosphorous	Sulphur	Molybdenum, Silicon

For hydroponic spinach production, nutrients were bought from PlantMe Agro Solutions Pvt Ltd., which came in two bottles as nutrient A and B (Plate 3.13). Nutrient A contains macronutrients and nutrient B contains micronutrients.

Plate 3.13 Nutrient solution

3.2 EXPERIMENTAL METHODOLOGIES

3.2.1 Site preparation

Land preparation was done inside the naturally ventilated polyhouse. Poly house was cleaned and levelled for giving stability to the structures. The polyhouse being levelled is shown in the plate 3.14. Then, the structures were installed in the polyhouse. It is shown in plate 3.15.

Plate 3.14 Site cleaning

Plate 3.15 Installation of structures inside the polyhouse

3.2.2 Seedling Preparation

Seeds were sown in pro tray with 50 holes in the nursery of Krishi Vigyan Kendra (KVK), Malappuram, Kerala on 29-03-2024. The media used was a mixture of vermiculite, perlite, coir pith compost and vermicompost in the ratio 1:1:2:1 (Plate 3.16). At 25th day after sowing, 1% urea spray was given. Transplanting was done after 30 days of sowing.

Plate 3.16 Seedling preparation

3.2.3 Transplanting of spinach

One month old seedlings were transplanted (Plate 3.17) to both structures on 29-04-2024. In the new developed structure, spinach was transplanted by rolling inside the sponge, whereas, in the existing structure it is placed in net cups along with clay pebbles as an inert growing medium.

Plate 3.17 Transplanting of spinach

3.2.4 Calibration of digital pH meter

Calibration is the process of adjusting a measuring instrument to ensure its accuracy and reliability. It involves setting reference points to guarantee that the meter provides correct readings. This calibration is essential due to factors like electrode aging, environmental changes, and manufacturing variations.

pH buffer solutions are needed for calibration of digital pH meter (Plate 3.18). They were prepared using pH 4, 7 and 9.2 buffer capsules by dissolving it in distilled water to create standard solutions of pH 4, 7 and 9.2 respectively. The electrode was immersed in calibration solution. Some adjustments were made to match the pH to the standard solution. After the calibration, the electrode is rinsed with distilled water and used for measuring pH.

Plate 3.18 Digital pH meter

3.2.5 Calibration of digital TDS/conductivity meter

Calibration of digital TDS/conductivity meter was done using buffer solution as shown in plate 3.19. The buffer solution used in this study is 0.1 N KCl, which is prepared by dissolving 0.745 g KCl in 100ml distilled water. The calibration is done by immersing the meter's probe in the buffer solution. Then the meter should display 12.8 mS/cm for EC and 7.4 ppt for TDS. If the output is not the required value, minor adjustments can be done with respective screw.

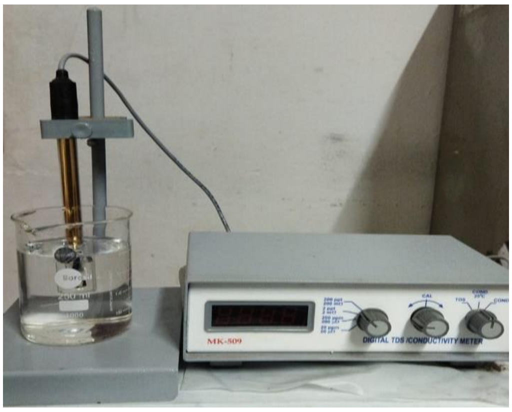


Plate 3.19 Digital TDS/conductivity meter

3.2.6 Monitoring of parameters

Monitoring parameters ensures that plants receive the right nutrients at the right concentrations. Regular monitoring helps detect any changes or imbalances in the system early, allowing for prompt adjustments and prevention of plant stress, nutrient deficiencies, or toxicities.

3.2.6.1 Microclimatic parameters

Temperature, Relative Humidity (RH), Photosynthetically Active Radiation (PAR) and Light intensity were observed inside and outside of the polyhouse on daily basis from 11 AM to 5 PM with two hours interval.

i. **Temperature and Relative humidity**: It is measured using Zeal Masons Pattern Hygrometer P2505 (Plate 3.20), which is a hygrometer consisting of two thermometers, wet-bulb and dry-bulb. The wet bulb is covered with a porous fabric which is maintained saturated with water. They are used to determine humidity through evaporative cooling. Humidity in the air is calculated by using psychrometric chart.

Plate 3.20 Hygrometer

ii. **Photosynthetically Active Radiation**: The radiation that drives photosynthesis is referred to as Photosynthetically Active Radiation (PAR) and a device that measures PAR is a called a PAR sensor or a PAR meter. In this study PAR is measured by MQ-300X: Line Quantum with 3 sensors and Handheld Meter (Plate 3.21). The working principle of a PAR quantum sensor involves the measurement of photons within a specific spectral range crucial for photosynthesis, *i.e*. 400-700 nm (Jegan *et al*., 2022).

Plate 3.21 PAR sensor

Plate 3.22 Monitoring of PAR

iii. **Light intensity**: A lux meter is a handheld device for measuring brightness or light intensity. The lux is a unit of measurement of brightness, or more accurately, illuminance. A lux meter works by using a photo cell to capture light. The meter then converts this light to an electrical current. In this study HTC LX-103 Digital Lux Meter is used (Plate 3.23).

Plate 3.23 Digital Lux meter

3.2.6.2 Nutrient solution parameters

In hydroponics, because of the limited nutrient-buffering capacity of the system and the ability to make rapid changes, careful monitoring of the nutrient solution is necessary. The frequency and volume of the nutrient solution applied depends on the type of substrate, the crop and growth stage, the size of the container, the irrigation systems used, and the prevailing climatic conditions. Depending on the stage of plant development, some elements in the nutrient solution will be depleted more quickly than others and as water evaporates from the nutrient solution, the fertilizer becomes more concentrated and can burn plant roots (Moaed, 2022).

i. **pH:** pH is a measure of the hydrogen ion concentration of a solution. The pH of the plant root environment is an important factor affecting the uptake of many nutrients. Recommended pH for spinach cultivation is 5.5–6.5 (Saaid *et al.*, 2020).

ii. **Electrical Conductivity (EC)**: EC is an index of salt concentration and an indicator of electrolyte concentration of solution. It is related to the number of ions available to plants at the root zone (Moaed, 2022). The total ionic concentration of a nutrient solution determines the growth, development and production of plants (Libia and Fernando, 2012).

    EC of the nutrient solution was monitored using Digital TDS/conductivity meter. It was maintained between 1.8–2.3 dSm^{-1} for the entire crop period. If EC of the nutrient solution was not within the specified range, nutrients A+B and water were added to correct EC value.

iii. **Total Dissolved Solids (TDS):** TDS refers to the number of substances that have been dissolved in the liquid. It is expressed in parts per million (ppm). For spinach, the TDS was kept between 200-450 ppm. If it was not within the specified range, nutrients A+B and water were added to correct EC value.

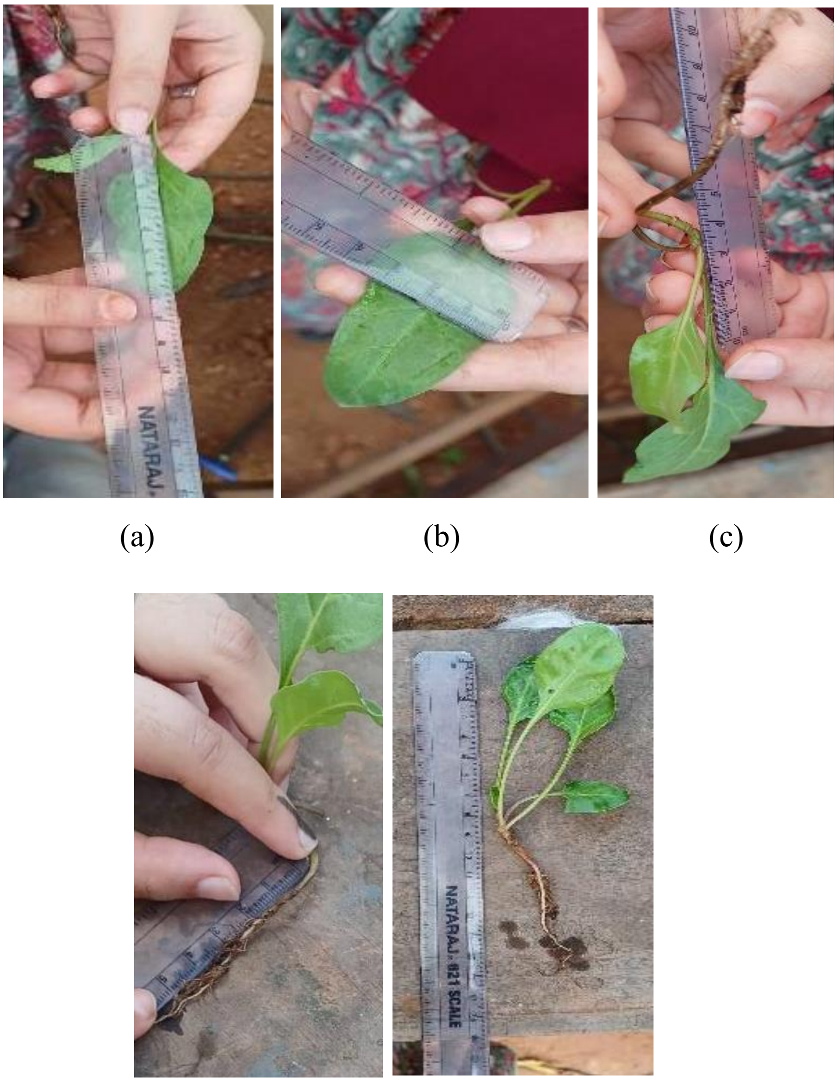
Table 3.5 Recommended TDS level for different crop period

Plant growth period	Grow A ml/20litre	Grow B ml/20litre	Recommended TDS Level
Week 1	20 ml	20 ml	200-250 ppm
Week 2	+10 ml	+10 ml	250-300 ppm
Week 3	+10 ml	+10 ml	300-350 ppm
Week 4 onwards maintain TDS	+20 ml	+20 ml	400-450 ppm

3.2.6.3 Biometric parameters

Monitoring biometric parameters in hydroponics is crucial for ensuring healthy plant growth and maximizing yield. Biometric parameters are measurements related to plant health and development, such as plant height, leaf size and root development. Changes in biometric parameters can indicate potential problems such as nutrient deficiencies, pests, diseases, or suboptimal environmental conditions.

i. **Plant height (cm):** The vertical length of a plant from the base to the topmost point is measured. It is an indicator of overall plant growth and development.
ii. **Number of leaves:** The total number of leaves on a plant is counted. It helps assess plant's ability to photosynthesize and can indicate growth stage.
iii. **Leaf length (cm)**: The longest dimension of a leaf is measured from its base to its tip. Leaf length can indicate the plant's growth and health status and may reflect the effects of environmental conditions.
iv. **Leaf width (cm)**: This is the widest part of a leaf. It is measured from one edge to the other at the leaf's broadest point. It is also an indicator of growth and health.
v. **Shoot length (cm)**: For this the length of the above-ground part of the plant, including stems and branches is measured. It is important for understanding overall plant structure and can impact light exposure and nutrient allocation.
vi. **Root length (cm)**: The length of the root system of the plant is measured. Healthy root growth is crucial in hydroponics for water and nutrient uptake and is an important parameter for assessing overall plant health.



(a) (b) (c)

(d) (e)

Plate 3.24 Measuring (a) Leaf length (b) Leaf width (c) Shoot length (d) Root length (e) Plant height

3.2.7 Harvesting of spinach

First harvest of the crop was done 28 days after transplanting on 25-05-2024.

Plate 3.25 Harvesting of spinach

3.3 DETAILS OF EXISTING STRUCTURE

NFT hydroponics system developed by Nandhini, 2022 was used for comparison. The system operated as a closed loop, utilizing four PVC pipes of 1.4 m length, 90 mm diameter, positioned one above the other. The frame and support is maintained at an angle of inclination of 45°. The setup consists of a nutrient mixing bucket of 15 L capacity and supply bucket of 20 L capacity (Plate 3.26). Pump of 45 W is kept inside nutrient mixing bucket. Nutrient solution from nutrient mixing bucket is pumped to supply bucket. From supply bucket it flows through the PVC pipes and reach back to the nutrient bucket by gravity and circulation continued.

Plate 3.26 Existing hydroponic system

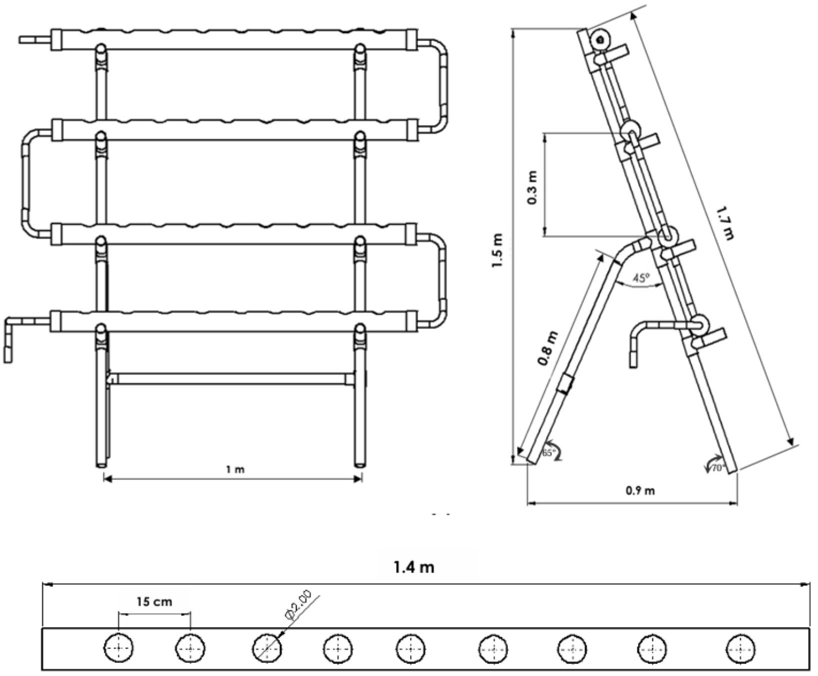


Fig. 3.2 Experimental design of existing system (source: Nandhini, 2022)

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

Results obtained from the study “Development and Performance Evaluation of an affordable hydroponic structure” are discussed in this chapter after analysing the observations taken during the course of work using the methodologies described in the chapter materials and methods.

In this study, spinach was cultivated for a crop period of 28 days (4 weeks) in the developed hydroponics system. Microclimatic parameters, nutrient solution parameters, biometric and yield parameters of the crop were observed and evaluated during crop growth. The achieved results of the experiment supported with suitable discussions are presented in this chapter. The study was done inside the naturally ventilated polyhouse (Area-213 m^2) of the Department of Irrigation and Drainage Engineering, KCAET, Tavanur. Out of that, 1.91 m^2 area was used for hydroponic spinach cultivation in both the structures. Spinach was the only crop inside the polyhouse.

4.1 OBSERVATION ON MICROCLIMATIC PARAMETERS

Microclimatic parameters viz. dry bulb temperature, wet bulb temperature, relative humidity, photosynthetically active radiation and light intensity were observed both inside and outside the polyhouse for the crop period of 4 weeks. Hygrometer was used to measure the dry and wet bulb temperature. By using the psychrometric chart, relative humidity was calculated from the dry and wet bulb temperatures. The digital lux meter was used to measure the light intensity. All the parameters were observed inside and outside the polyhouse, four times a day from morning 11 AM to evening 5 PM with two hours intervals. Average of all microclimatic parameters at a time for each week is calculated as shown in Tables 4.1 to 4.5.

Table 4.1 Average values of dry bulb temperature (°C) observed inside and outside the polyhouse

Week	Time	Inside	Outside
Week 1	11 AM	32.9	34.7
	1 PM	35	37.3
	3 PM	33	35.4
	5 PM	32	33.4
Week 2	11 AM	30.8	31.4
	1 PM	34.4	35
	3 PM	35.3	37.1
	5 PM	31.6	31.8
Week 3	11 AM	30.4	30.8
	1 PM	30.7	31.9
	3 PM	31.2	31.3
	5 PM	29.6	29.5
Week 4	11 AM	30	30.5
	1 PM	30.1	31
	3 PM	29.2	30.2
	5 PM	28.2	29

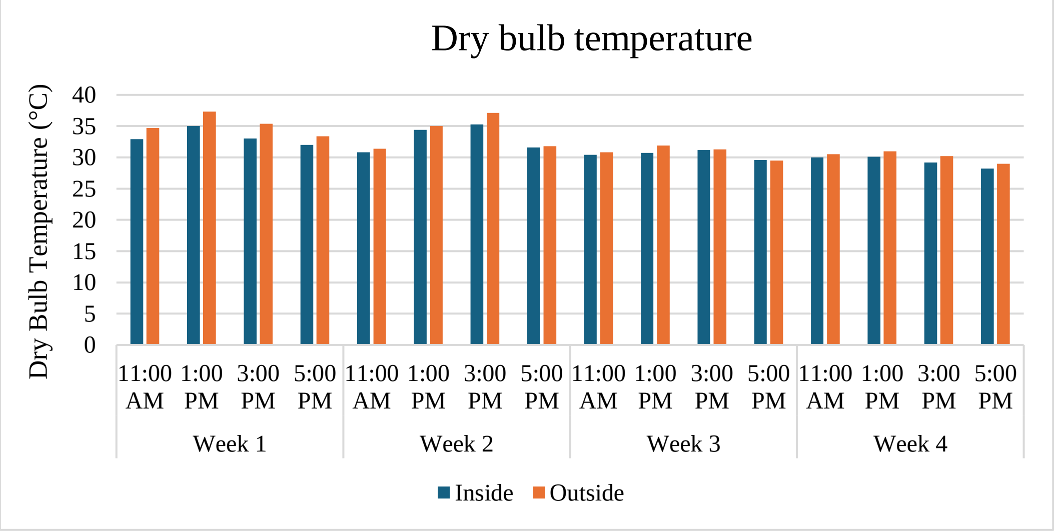


Fig. 4.1 Variation of dry bulb temperature inside and outside the polyhouse during the crop growth period

Table 4.2 Average values of wet bulb temperature (°C) observed inside and outside the polyhouse

Week	Time	Inside	Outside
Week 1	11 AM	29.4	29.7
	1 PM	30.1	30.7
	3 PM	30	30.7
	5 PM	28.8	29.5
Week 2	11 AM	28.4	28.7
	1 PM	30	30.1
	3 PM	30.2	32.1
	5 PM	29.3	28.8
Week 3	11 AM	28.2	28.4
	1 PM	28.3	28.5
	3 PM	28.7	29.1
	5 PM	28.4	29
Week 4	11 AM	30	30.5
	1 PM	30.1	31
	3 PM	29.2	30.2
	5 PM	28.2	29

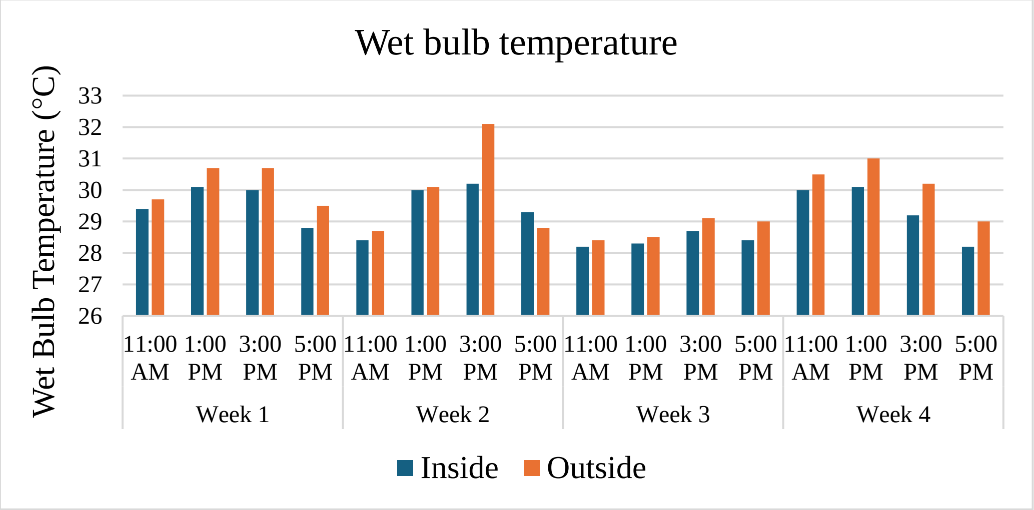


Fig. 4.2 Variation of wet bulb temperature inside and outside the polyhouse during the crop growth period

Normally, dry bulb temperature and wet bulb temperature inside the polyhouse is greater than outside. As spinach is the crop used for the study, it is necessary to control the temperature for its cultivation. It can be observed from Fig. 4.1 and Fig. 4.2 that by the use of foggers and exhaust fans the temperature were kept desirable. Other temperature regulators like cooling systems and ventilations can also be used.

Table 4.3 Average values of relative humidity (%) observed inside and outside the polyhouse

Week	**Time**	**Inside**	**Outside**
Week 1	11 AM	77.8	70.1
	1 PM	71	62.9
	3 PM	80.3	71.9
	5 PM	78.4	75.3
Week 2	11 AM	84.3	82.4
	1 PM	74	71.1
	3 PM	69.87	70.8
	5 PM	84.8	80.8
Week 3	11 AM	85.1	84
	1 PM	84.1	79.6
	3 PM	83.3	81.8
	5 PM	91.4	89.9
Week 4	11 AM	86.2	83.7
	1 PM	79.7	78.5
	3 PM	84.2	86.5
	5 PM	92.5	85.8

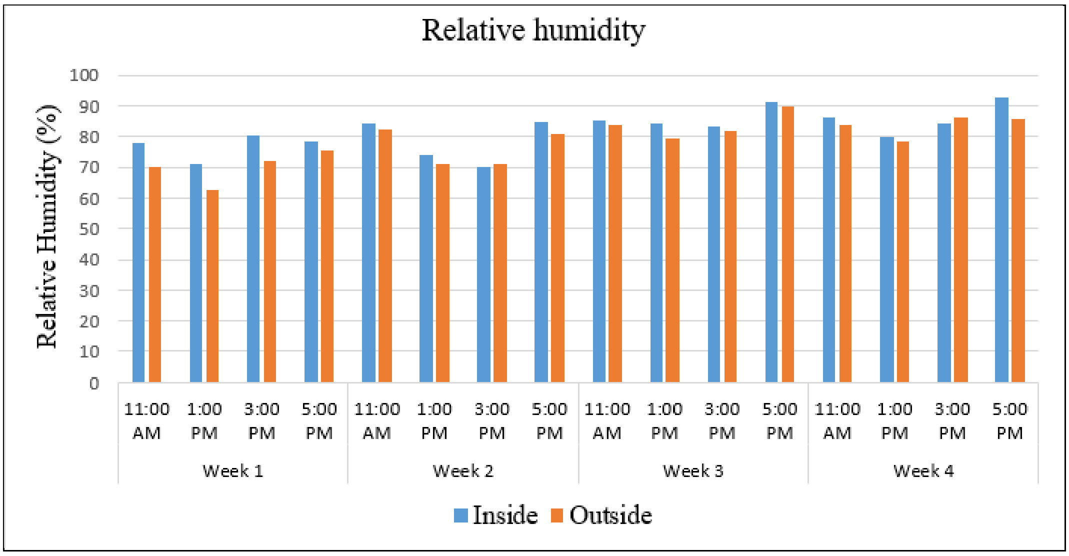


Fig. 4.3 Variation of relative humidity inside and outside the polyhouse during the crop growth period

RH is lesser inside the polyhouse compared to outside environment. With the use of foggers it was kept higher than the outside environment.

Table 4.4 Average values of light intensity (lx) observed inside and outside the polyhouse

Week	**Time**	**Inside**	**Outside**
Week 1	11 AM	11456.4	50743.6
	1 PM	13382.1	66664
	3 PM	10842.1	55541.4
	5 PM	9061.4	22201.6
Week 2	11 AM	9898.8	29806.7
	1 PM	13903.1	46915.7
	3 PM	12150.7	48510
	5 PM	4513.1	14088.6
Week 3	11 AM	7882.2	20882
	1 PM	7383.5	22998.6
	3 PM	7851.7	22763.9
	5 PM	2986.5	11155.9
Week 4	11 AM	5902.5	21211.3
	1 PM	7238.5	13362.8

	3 PM	2677	11661.5
	5 PM	1560.5	6620.75

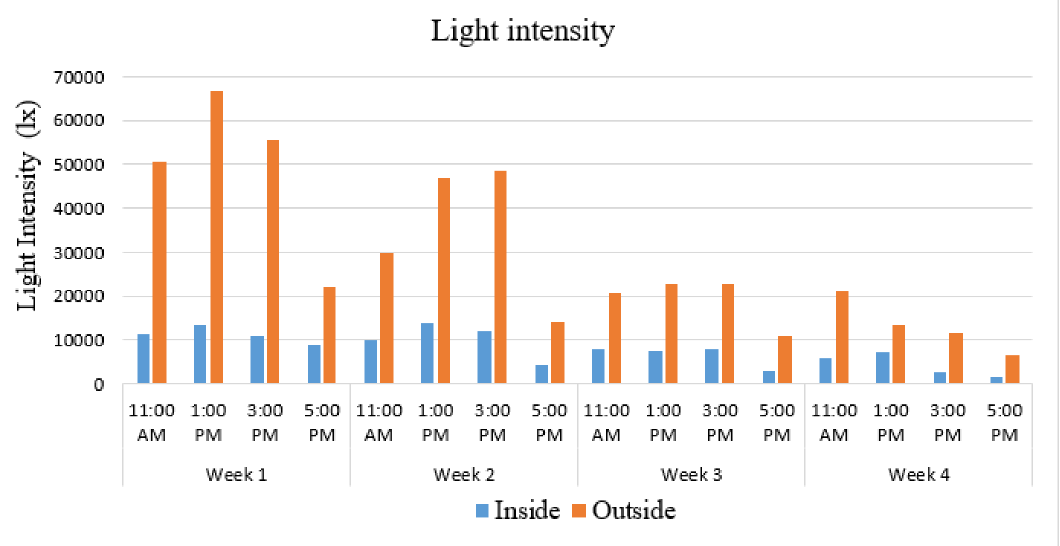


Fig. 4.4 Variation of light intensity inside and outside the polyhouse during the crop growth period

Table 4.5 Average values of photosynthetically active radiation (PAR) (μmol m^{-2} s^{-1}) observed inside and outside the polyhouse

Week	**Time**	**Inside**	**Outside**
Week 1	11 AM	471.8	1217.2
	1 PM	659.7	1748
	3 PM	599.5	1512.4
	5 PM	298.8	603
Week 2	11 AM	271.8	1082.4
	1 PM	369	1564.7
	3 PM	372.5	1466.4
	5 PM	116.5	421.2
Week 3	11 AM	223.2	649.5
	1 PM	224.2	673.1
	3 PM	168	599.6
	5 PM	108	353

Week 4	11 AM	282.5	535.4
	1 PM	221	556.5
	3 PM	88.5	352.5
	5 PM	49.2	253

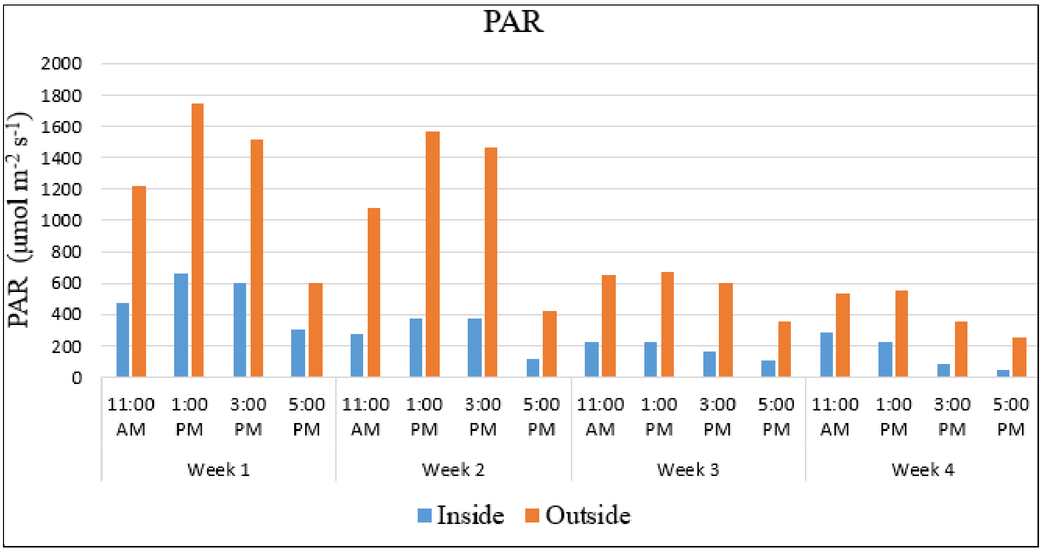


Fig. 4.5 Variation of photosynthetically active radiation inside and outside the polyhouse during the crop growth period

Fig 4.4 and Fig 4.5 showed that light intensity and PAR is less inside the polyhouse due to the shading nets, which are designed to protect plants from excessive sunlight and heat, thereby creating a more controlled and conducive growing environment. However, the presence of uncleaned cladding material further diminishes light penetration, potentially leading to suboptimal light conditions. Yet, the accumulation of dirt and debris on cladding materials exacerbates light reduction, which can hinder photosynthesis and affect plant development adversely. Therefore, while shading nets serve an essential role in managing light and temperature, maintaining clean cladding materials is crucial to ensure sufficient light availability for optimal plant health and productivity.

4.2 OBSERVATION ON BIOMETRIC PARAMETERS

Data on observations viz. number of leaves, leaf length, leaf width, shoot length, root length and plant height were observed at the time of transplanting and at the end of each week of crop growth as shown in Table 4.6, Table 4.7, Table 4.8, Table 4.9, Table 4.10 and Table 4.11.

4.2.1 Number of leaves

The number of leaves were measured for each row in both structures and the average of it in each week is given in the Table 4.6.

Table 4.6 Number of leaves

Week	**Developed structure**	**Existing structure**
At the time of transplanting	3	3
Week 1	3	4
Week 2	4	5
Week 3	5	6
Week 4	6	7

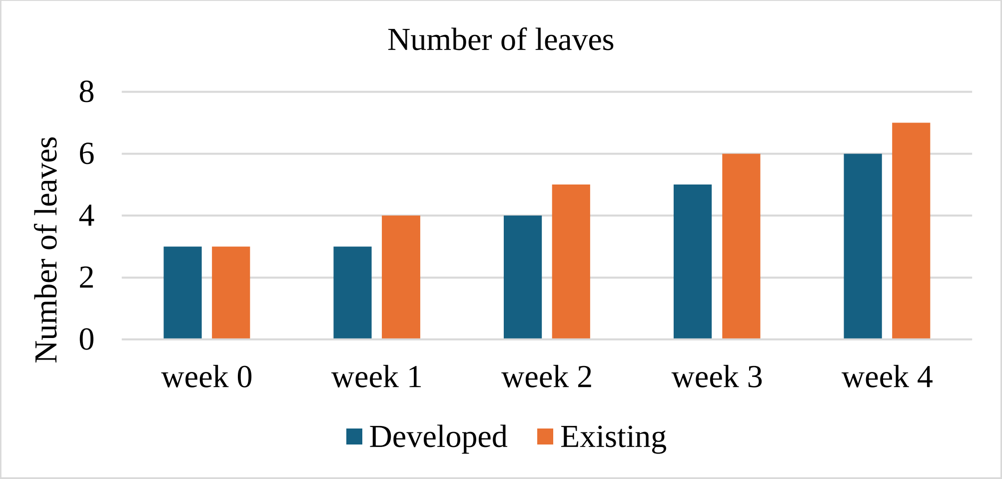


Fig. 4.6 Number of leaves in both structures

Fig. 4.6 shows that number of leaves were more in the existing structure than the developed.

4.2.2 Leaf length

Leaf length was measured for each row in both structures and the average of it in each week is given in the Table 4.7.

Table 4.7 Leaf length (cm)

Week	**Developed structure**	**Existing structure**
At the time of transplanting	4.5	5.4
Week 1	5.4	6.3
Week 2	6.2	7
Week 3	7.5	8
Week 4	8.6	9.2

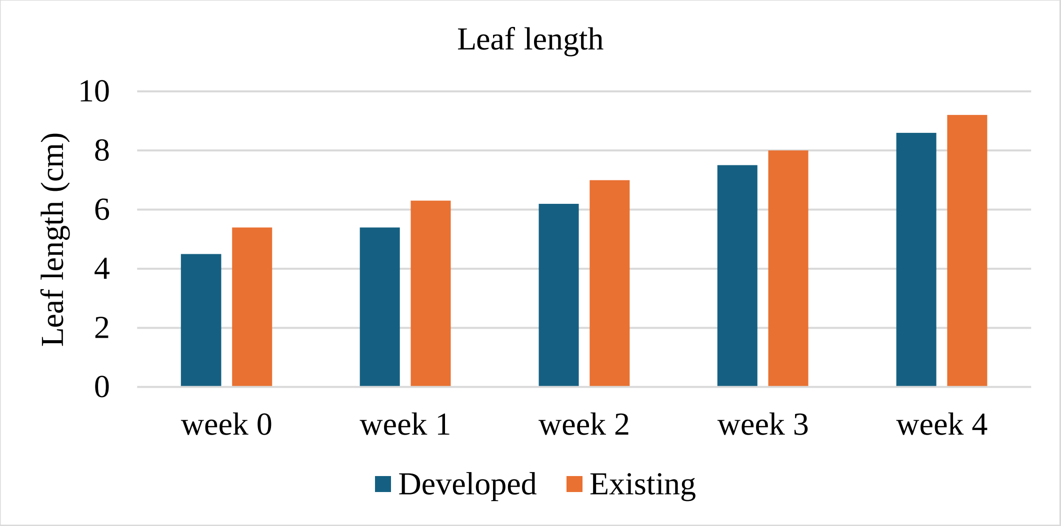


Fig. 4.7 Leaf length in both structures

Fig. 4.7 shows that leaf length was slightly higher in the existing structure than the developed.

4.2.3 Leaf width

Leaf width was measured for each row in both structures and the average of it in each week is given in the Table 4.8.

Table 4.8 Leaf width (cm)

Week	**Developed structure**	**Existing structure**
At the time of transplanting	3.2	3.6
Week 1	3.9	3.9
Week 2	4	4.4
Week 3	5.1	5.6
Week 4	5.8	6.1

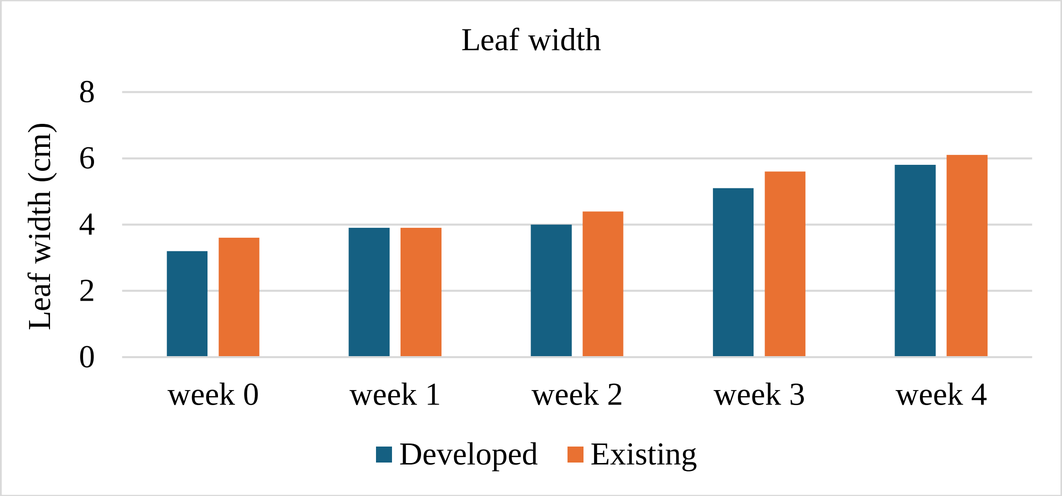


Fig. 4.8 Leaf width in both structures

Fig. 4.8 shows that leaf width in the existing structure were almost similar to the developed.

4.2.4 Shoot length

Shoot length was measured for each row in both structures and the average of it in each week is given in the Table 4.9.

Table 4.9 Shoot length (cm)

Week	**Developed structure**	**Existing structure**
At the time of transplanting	4.5	4.8

Week 1	5.6	5.9
Week 2	5.8	6.6
Week 3	7	7.1
Week 4	8.3	8.7

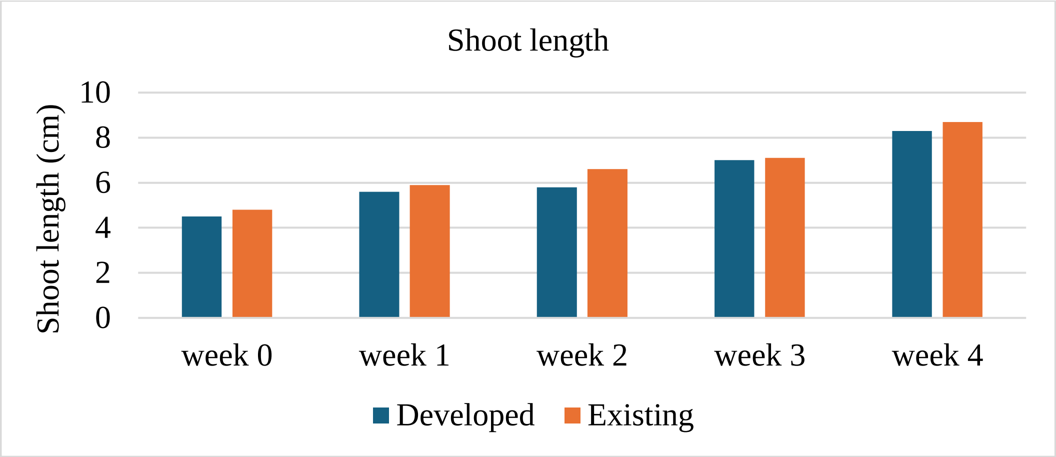


Fig. 4.9 Shoot length in both structures

Fig. 4.9 shows that shoot length in the existing and the developed structure were almost same.

4.2.5 Root length

Root length was measured for each row in both structures and the average of it in each week is given in the Table 4.10.

Table 4.10 Root length (cm)

Week	Developed structure	Existing structure
At the time of transplanting	6.5	5.8
Week 1	9	10
Week 2	12.5	13.5
Week 3	15.4	18.2
Week 4	21.7	24

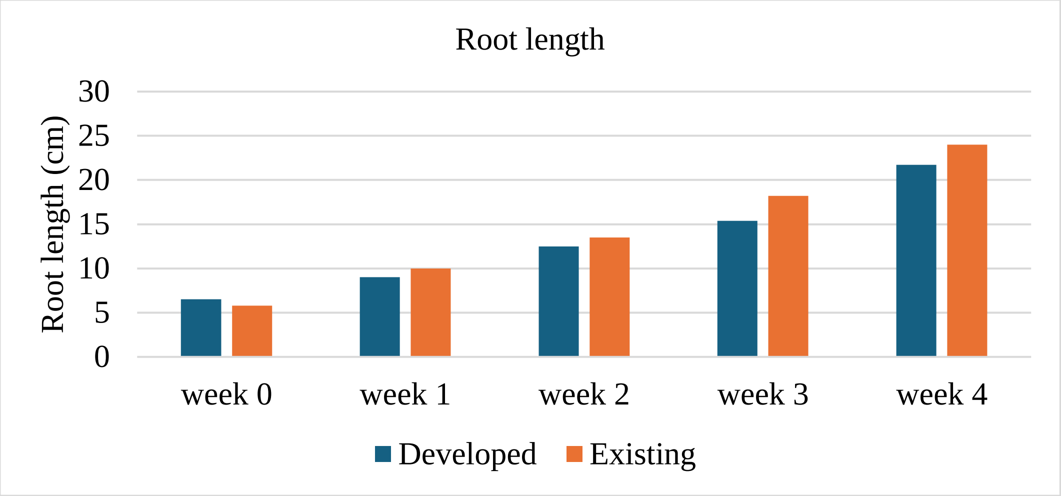


Fig. 4.10 Root length in both structures

Fig. 4.10 shows that root length in the existing structure were higher than the developed towards the end of crop growth period.

4.2.6 Plant height

Plant height was measured for each row in both structures and the average of it in each week is given in the Table 4.11

Table 4.11 Plant height (cm)

Week	Developed structure	Existing structure
At the time of transplanting	15.5	16
Week 1	20	22.2
Week 2	24.5	27.2
Week 3	29.9	33.3
Week 4	38.5	42

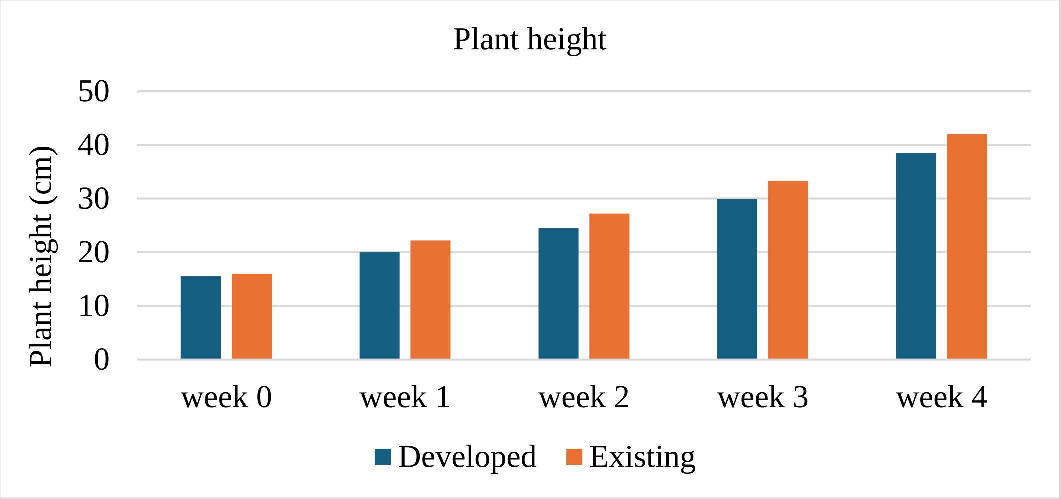


Fig. 4.11 Plant height in both structures

Fig. 4.11 shows that plant height in the existing structure were slightly higher than the developed towards the end of crop growth period.

4.3 YIELD

After 28 days of growth, spinach crops were harvested for the first time by plucking the leaves, weight of which was taken to calculate the yield. Yield obtained for the developed structure was 106 g per 0.36 m^2 (Plate 4.1).

(a) (b)

Plate 4.1 (a) Harvested spinach and (b) Weighing of the harvested spinach

In this study both the structures were powered by solar energy. Due to sudden change in weather conditions, battery could not store sufficient energy for operating both the system. As an alternative KSEB connection was utilised for the developed structure during night. The existing structure failed to connect to KSEB due to its structural limitations. Therefore, there was no water supply to the roots during night. Thereby, the plants wilted few days before harvest. Hence, the existing structure couldn't give yield.

(a) (b)

Plate 4.2 Spinach in the developed structure: (a) at the time of transplanting (b) at the time of harvest

Plate 4.3 Spinach in the existing structure at the time of transplanting

Plate 4.4 Spinach in the existing structure few days before harvest

4.4 COMPARISON OF DEVELOPED AND EXISTING STRUCTURE

Table 4.12 Comparison of developed and existing structure

Compared items	**Developed structure**	**Existing structure**
Structural cost	3982	6400
Area occupied	0.36 m^2	1.55 m^2
Number of plants	16	36
Electricity consumption	1.44 KWh	1.08KWh

4.5 MAINTENANCE OF THE SYSTEM

The socket should be protected from water to avoid short circuiting. So, the socket was kept inside a case as foggers were used. The submersible pump should not be operated without water. As there is no automation, nutrient solution should be maintained manually in the system, or else pump will be damaged. Neem oil spray can be used for controlling small insects.

4.6 LIMITATIONS

Both of the experimental structures were powered by solar energy. Due to sudden change in weather conditions, battery could not store sufficient energy for operating both the system. As an alternative KSEB connection was utilised for the developed structure during night. The existing structure failed to connect to KSEB due to its structural limitations.

The existing structure needs to be cleaned frequently. The developed structure once installed can’t be opened as it can disturb the system.

4.7 FUTURE SCOPE OF THE STUDY

Productivity in the system can be improved by increasing the number of buckets and holes in each bucket for keeping plants. This trial system can be adapted not only for leafy vegetables but also for ornamental flowers. Automation can be incorporated in the developed structure to grow crops on a large scale.

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Vertical hydroponics has emerged as a response to the increasing global demand for food production amid growing urbanization and limited agricultural land. This innovative farming technique leverages vertical space and soilless cultivation methods to maximize crop yields in compact areas, making it particularly suitable for urban environments. As traditional farming faces challenges such as soil degradation, water scarcity, and the impact of climate change, vertical hydroponics offers a sustainable alternative. By recirculating water and nutrients through a closed-loop system, it significantly reduces water usage compared to conventional farming. Moreover, vertical hydroponics allows for precise control over growing conditions, leading to higher productivity and consistency in crop quality. This approach not only addresses food security issues but also promotes the cultivation of fresh produce closer to urban consumers, reducing transportation costs and carbon emissions. Despite these advantages, challenges such as high initial setup costs, technical complexities, and energy demands for lighting and climate control must be addressed to fully realize the potential of vertical hydroponics.

Hence, the current study entitled "Development and Performance Evaluation of an affordable hydroponic structure" was conducted in a naturally ventilated polyhouse, located at Kelappaji College of Agricultural Engineering and Technology, Tavanur during April-May 2024. This study was undertaken to develop a simple vertical farming hydroponic system which can be used to grow leafy vegetables inside polyhouse. A vertical hydroponic structure was constructed with buckets arranged in vertically stacked layers. NFT hydroponics system developed by Nandhini, 2022 was used for comparison. Environmental parameters such as relative humidity, light intensity, PAR and temperature were observed inside and outside the polyhouse during the study. Spinach was grown for 28 days (4 weeks) in both systems. The nutrient solution was used to supply the nutrients.

Nutrient solution parameters were observed continuously during the crop period. The optimum level of pH between 5.5-6.5 for the nutrient solution was maintained. EC of the nutrient solution was maintained in between 1.8-2.3 dSm^{-1} during the growth period of the crop. TDS of the nutrient solution was maintained between 200-450 ppm throughout the growing period.

The gathered microclimatic data revealed that the hourly average air temperature inside the polyhouse ranges between 26℃ and 40℃ during the crop period. The maximum temperature was usually found between 1 PM to 3 PM (30 to 40℃). Minimum temperature was found between 11 AM to 12 PM (26 to 27 ℃). During day time air temperature varied between 25 to 41℃ during the crop period. Hourly average RH inside the polyhouse ranges between 69.87% and 92.5% during the crop period. Maximum light intensity and PAR measurements was observed between 1 PM and 3 PM. Biometric observations gave almost similar results from both structures. Whereas while considering cost economics and land utilization, the developed structure appears to be more beneficial.

The developed system was a small one. For the further improvement of the system, more buckets and more holes in each bucket can be made for keeping plants. This project was conducted in a small-time frame, so only one time harvest of spinach was done. This system can also be used for other leafy vegetables and ornamental flowers.

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Appendices

APPENDIX I

Details of microclimatic parameters

Daily dry bulb temperature (°C) data during crop period (inside polyhouse)

Day	11 AM	1 PM	3 PM	5 PM
1	35	37	36	34
2	31	33	33	32
3	32.5	35	32	31
4	32	36	31.5	32.5
5	33	34	33	31
6	31	38	30	34
7	36	32	36	30
8	32	31	37	34
9	29	37	36	32
10	30.5	34	37	30
11	35	39	37	32
12	31	40	37	33
13	27	28	31	29
14	31	32	32	31
15	29	30	31.5	30
16	30	31	32	30.5
17	28	30	31	29
18	29	27	28	30
19	29	26	29	26
20	36	35	33	31
21	32	36	34	31
22	29	29	29	28
23	29	30	28	28
24	28	28.5	29	28
25	34	33	31	29

Daily wet bulb temperature (°C) data during crop period (inside polyhouse)

Day	**11AM**	**1 PM**	**3 PM**	**5 PM**
1	30.5	31	32	29.5
2	30.5	31	31	29.5
3	27	32	31.5	28
4	29	30	27.5	29.5
5	29	28	30	27
6	30	29	28	29
7	30	30	30	29
8	30	30	31	30
9	29	31	30.5	30
10	28	29	30	30
11	29	31	30	28
12	28	32	31	29
13	26	27	29	28
14	29	30	30	30
15	27.5	28	29	29
16	28	29	30	29
17	27	28	29	29
18	27	26	27	28
19	27	26	28	26
20	30	30	28	29
21	31	31	30	29
22	28	28	28	27
23	28	26	26	27
24	26	26.5	27	27
25	30	28	27	28

Daily Relative humidity (%) data during crop period (inside polyhouse)

Day	11 AM	1 PM	3 PM	5 PM
1	72.1	64.9	75.3	71.6
2	96.4	86.5	86.5	83.1
3	65.1	80.8	96.5	79.5
4	79.9	64.4	73.4	80
5	74.1	63.2	80.2	73.2
6	92.9	51	85.8	68.8
7	64.4	86.3	64.4	92.8
8	86.3	92.9	64.9	74.5
9	100	64.9	67.1	86.3
10	82.6	68.8	59.9	100
11	63.8	56.3	59.9	73.7
12	79.5	56.9	64.9	74.1
13	92.3	92.5	86.1	92.6
14	86.1	86.3	86.3	92.9
15	89.1	85.8	82.9	92.8
16	85.8	86.1	86.3	89.4
17	92.5	85.8	86.1	100
18	85.6	92.3	92.5	85.8
19	85.6	100	92.6	100
20	64.4	69.3	68.3	86.1
21	93	69.8	74.5	86.1
22	92.6	92.6	92.6	92.5
23	92.6	72.7	85.3	92.5
24	85.3	85.4	85.6	92.5
25	74.5	68.3	73.2	92.6

Daily Light intensity (lx) data during crop period (inside polyhouse)

Day	11 AM	1 PM	3 PM	5 PM
1	12800	14700	12500	8820
2	14750	14000	11650	6725
3	15525	19300	12575	10365
4	12400	14650	15150	12000
5	8735	9530	7440	3445
6	9130	11385	8720	19015
7	6855	10110	7860	3060
8	13750	16745	13600	3995
9	11605	16200	10730	3527
10	12677	16472	14175	7530
11	8200	16510	12315	5585
12	6655	16865	9140	1455
13	2295	2565	12860	3550
14	14110	11965	12235	5950
15	8202	7265	12547	4750
16	11156	11615	12391	5350
17	9679	10440	12469	5050
18	919	1715	990	2310
19	4625	2845	2445	1341
20	14905	10655	4485	1580
21	5690	7150	9635	525
22	3510	4530	1270	1110
23	1700	7850	1392	974
24	2100	6794	1576	993
25	16300	9780	6470	3165

Daily Photosynthetically Active Radiation (PAR) (µmol m^{-2} s^{-1}) data during crop period (inside polyhouse)

Day	11 AM	1 PM	3 PM	5 PM
1	856	862	910	483
2	802	956	964	422
3	355	1024	937	439
4	787	990	810	515
5	223	248	153	68
6	110	305	195	90
7	170	233	228	75
8	347	389	360	121
9	294	384	294	98
10	320	386	342	45
11	193	523	395	154
12	180	525	444	67
13	101	113	393	131
14	468	263	380	200
15	284	386	188	165
16	376	324	284	182
17	203	182	173	131
18	31	40	63	81
19	135	114	90	33
20	334	285	137	79
21	200	239	241	85
22	125	172	55	31
23	95	210	20	25
24	335	237	103	55
25	575	265	176	86

Daily dry bulb temperature (°C) data during crop period (outside polyhouse)

Day	11 AM	1 PM	3 PM	5 PM
1	36	38	37	35
2	33	35	34	33
3	34	36	35	34
4	34	37	34	33
5	35	36	36	33
6	32	41	32	35
7	39	38	40	31
8	33	34	40	35
9	30	39	37	34
10	32	35	39	29
11	34	37	34	32
12	31	38	39	34
13	26	29	35	29
14	34	33	36	30
15	30	31	32	31
16	31	32	34	31
17	30	33	34	31
18	30	29	28	29
19	27	25	29	28
20	36	38	31	29
21	32	35	33	31
22	29	30	30	29
23	29	31	29	28
24	29	30	30	29
25	35	33	32	30

Daily wet bulb temperature (°C) data during crop period (outside polyhouse)

Day	11 AM	1 PM	3 PM	5 PM
1	31	32	33	30
2	31	31	32	31
3	29	33	32	30
4	30	31	29	30
5	29	28	29	27
6	29	31	29	28.5
7	29	29	31	30
8	29	31	39	29
9	30	31	31	31
10	29	31	32	28
11	28	30	31	29
12	28	31	31	28
13	26	27	30	28
14	31	30	31	29
15	28	29	30	30
16	29	30	31	30
17	28	29	30	30
18	29	27	27	28
19	26	25	27	25
20	29	30	28	29
21	30	30	29	28
22	29	29	30	28
23	27	28	28	27
24	27	27	28	27
25	29	27	27	26

Daily Relative humidity (%) data during crop period (outside polyhouse)

Day	11 AM	1 PM	3 PM	5 PM
1	69.8	65.5	75.7	69.3
2	86.5	74.9	86.8	86.5
3	68.8	81.1	80.8	74.5
4	74.5	64.9	68.8	80.2
5	63.8	54.3	59.2	62.6
6	79.9	48.8	79.9	61.2
7	47.4	51	52.4	92.9
8	74.1	80.5	93.8	63.8
9	100	56.3	64.9	80.5
10	79.9	74.9	61	92.6
11	63.2	59.9	80.5	79.9
12	79.5	60.5	56.3	63.2
13	100	85.6	69.3	92.6
14	80.5	80.2	69.8	92.8
15	85.8	86.1	86.3	92.9
16	86.1	86.3	80.5	92.9
17	85.8	74.1	74.5	92.9
18	92.8	85.6	92.5	92.6
19	92.3	100	85.6	78.3
20	59.2	55.7	79.5	100
21	86.3	69.3	74.1	79.5
22	100	92.8	100	92.6
23	85.6	79.5	92.6	92.5
24	85.6	79.1	85.8	85.6
25	63.8	62.6	67.7	72.7

Daily Light intensity (lx) data during crop period (outside polyhouse)

Day	**11 AM**	**1 PM**	**3 PM**	**5 PM**
1	40800	51700	50520	20350
2	62235	60320	56340	19850
3	36540	66548	54960	21366
4	52980	53280	53690	19520
5	73950	79100	72780	31750
6	41250	78900	52900	19575
7	47450	76800	47600	23000
8	67505	83350	62950	17830
9	23000	19850	50270	19415
10	30252	51600	39100	18550
11	15005	53300	48050	11150
12	12400	68250	55500	9635
13	5935	13460	38400	9590
14	54550	38600	45300	12450
15	30242	26030	41850	11020
16	20396	32315	38575	11735
17	25319	29172	30212	15377
18	12857	9743	7635	11240
19	10910	10730	10475	9824
20	28150	35500	3150	8570
21	18300	17500	27450	10325
22	6900	7450	7890	6892
23	12795	11347	10620	4536
24	10250	9904	10764	5060
25	54900	24750	17372	9995

Daily Photosynthetically Active Radiation (PAR) (µmol m^{-2} s^{-1}) data during crop period (outside polyhouse)

Day	11 AM	1 PM	3 PM	5 PM
1	1410	1564	1412	650
2	1390	1671	1732	614
3	1410	2193	1987	598
4	1170	1836	1400	677
5	1050	1250	1342	605
6	691	1923	1450	550
7	1400	1799	1264	527
8	1710	1898	1478	543
9	1335	1764	1571	336
10	1057	1745	1527	130
11	780	1846	1395	545
12	670	2321	1690	282
13	187	350	1045	497
14	1838	1029	1559	616
15	931	1032	894	567
16	987	1023	974	532
17	1040	990	862	391
18	280	302	208	294
19	310	354	262	204
20	637	592	417	257
21	362	419	580	226
22	292	382	160	114
23	240	326	107	53
24	993	916	650	565
25	616.5	602	493	280

APPENDIX II

Biometric parameters of spinach in the developed structure

Biometric parameters of spinach at the time of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	2	5	3.5	4.5	7	16.5
2nd row	2	4	3.1	4	5	13
3rd row	4	4	3	5	7.5	16.5
4th row	4	5	3.2	4.5	6.5	16

Biometric parameters of spinach after 1 week of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	4	5.6	4.17	6.22	9.5	21.3
2nd row	3	5.5	3.6	6.25	7.5	19.2
3rd row	2	6	3.17	4.52	10	20.5
4th row	2	4.65	4.74	5.41	9	19

Biometric parameters of spinach after 2 weeks of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	4	6	4.22	7.25	13	26.2
2nd row	5	6.65	4.25	5.35	11	23
3rd row	3	6.32	3.4	4	14	24.3
4th row	4	6	4.2	6.5	12	24.5

Biometric parameters of spinach after 3 weeks of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	5	6.8	4.95	6.3	15	28.1
2nd row	6	7.6	5.12	7.02	14.5	29.12
3rd row	5	8	4.62	6.8	17	31.8
4th row	5	7.5	5.72	8	15	30.5

Biometric parameters of spinach after 4 weeks of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	7	8	5.9	7.55	22	37.55
2nd row	7	8.3	6	8.9	20	37.2
3rd row	6	9.1	5.15	7.6	24	40.7
4th row	6	8.9	6.16	9	21	38.9

Biometric parameters of spinach in the existing structure

Biometric parameters of spinach at the time of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	4	5.2	3.8	5	7	17.2
2nd row	2	5	3	5	5	15
3rd row	3	6	3.9	4.5	6	16.5
4th row	3	5.4	3.6	4.7	5.4	15.5

Biometric parameters of spinach after 1 week of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	4	5.85	4.05	6.5	11	23.3

2nd row	4	6.7	3.4	6.5	9.7	22.9
3rd row	4	6.5	4.2	5	10	21.5
4th row	3	6.3	3.9	5.6	9.3	21.2

Biometric parameters of spinach after 2 weeks of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	6	7	4.6	7.6	14	28.6
2nd row	4	7.07	4.2	7.2	12.5	26.8
3rd row	5	7.1	4.5	5.8	14	26.9
4th row	4	7.2	4.2	5.9	13.4	26.5

Biometric parameters of spinach after 3 weeks of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	6	7.5	6	7.9	18	33.4
2nd row	5	7.9	5.5	7.6	17.2	32.7
3rd row	6	8.6	5.3	6.3	19	33.9
4th row	5	8	5.6	6.8	18.5	33.3

Biometric parameters of spinach after 4 weeks of transplanting

Plant	No. of leaves	Leaf length (cm)	Leaf width (cm)	Shoot length (cm)	Root length (cm)	Plant height (cm)
1st row	7	9.2	6.5	9	24	42.2
2nd row	7	8.5	6	8.5	23	40
3rd row	6	9.4	5.7	7.6	25	42
4th row	8	9.9	6.2	10	24	43.9

APPENDIX III

Structural cost:

SI. No.	Materials	Value (Rs.)
1	PVC pipe	971
2	Valve	299
3	Buckets	862
4	Pump	1850

DEVELOPMENT AND PERFORMANCE EVALUATION OF AN AFFORDABLE HYDROPONIC STRUCTURE

By

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ABSTRACT OF THESIS

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In

Agricultural Engineering

Faculty of Agricultural Engineering and Technology

KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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ABSTRACT

A study was conducted to develop a vertical hydroponics system and to compare the performance of the developed system with existing NFT hydroponics system. Both the structures were installed in naturally ventilated polyhouse, in the research plot of Department of Irrigation and Drainage Engineering situated near the LH KCAET, Tavanur, Kerala, during the period April-May 2024. The objective of this study is to develop a simple vertical farming hydroponic system which can be used to grow leafy vegetables inside polyhouse. Spinach was grown for 28 days (4 weeks) in both the system using nutrient solution as a growing media. Microclimatic parameters such as relative humidity, light intensity, photosynthetically active radiation and temperature were observed inside and outside the polyhouse during the study. Hourly average air temperature, RH and light intensity were varying from time to time during the crop period. Hence, exhaust fans and foggers were used to control the environment inside the polyhouse against the extreme climate. Nutrient solution parameters such as pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were monitored and maintained in the desirable range. Nutrient A, B and water were used for correction. Biometric parameters related to plant health and development, such as plant height, leaf size, root development are recorded in each week.

The study proved that the structure was affordable with utilisation of less area. Furthermore, the structure, with some modifications can help to increase the crop production and maximize the returns. Overall, hydroponic farming has a potential to provide fresh produce year-round and offers the prospect of solving problems that are integrated with conventional methods.